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A HISTORY OF A STUNTED BROOK TROUT POPULATION IN AN ALPINE LAKE: A LIFESPAN OF 24 YEARS [1]

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The last known survivor of an experimentally stocked population of brook trout lived well into its 24th year of life in a small, High Sierra lake. This extreme longevity doubles previous age records for the species and is attributed to a combination of food scarcity, low temperature, and a remote environment where the influence of angling was negligible. As a consequence of early overcropping and decimation of invertebrate food organisms, semistarvation and stunting continued throughout the lives of originally stocked trout. Natural propagation was repressed until age 16 years. Growth was near normal for the few second-generation fish, which arrived late enough to inherit improved forage due to attrition of the parent generation.

Laboratory culture of some of the aging trout (12–18 years) demonstrated capacity for regrowth with sustained nutrition. A breeding experiment with 14-year-olds produced no viable offspring, but cross-fertilization with young brook trout indicated limited fertility in both sexes at advanced age.

Histological evaluations at ages 12, 13, 14, and 18 years sought to correlate degenerative changes in vital systems with chronological age. Old trout were distinguishable from their young counterparts only by minor, "wear-and-tear" changes until very late in life. Gross developmental anomalies were found in generative cells and tissues of nearly all mature specimens examined but could not be definitely linked to physiological aging.

Fin-clipped individuals permitted identification of the stocked group for 19 years. Otoliths were used to verify ages up to 24 years.

PREFACE

Each spring Nature gently lifts an ermine cape from her High Sierra and majestically displays California's crown jewels: several thousand sapphire and emerald lakes placed with perfection in brilliant settings, gracing the crest of the Golden State for over 400 miles from the Kern Plateau to the Feather River. Yet despite their incomparable beauty and vast recreational potential, our high mountain lakes have been only sparsely studied and generally remain an enigma to the fishery management biologist.

This situation prompted the U.S. Fish and Wildlife Service to undertake the early limnological investigations of the Convict Creek Basin lakes 30 years ago. Although collection of data for a major report on that work ended in 1952, an experimental offshoot of the studies continued, quite unexpectedly, until 1974. What has resulted comprises the revelation of the world's oldest known brook trout population and a treasure chest of insight into its biology and environmental interactions, the principles of which are probably more typical than not of brook trout in high mountain lakes. Inasmuch as my area of responsibility includes the management of approximately 700 such lakes, I can attest to the need for this kind of information in our slow approach to optimum use of the resource.

Some shortcomings are understandable in a study which is pursued sporadically for many years. Because of the unusual circumstances, the editor of *Califor-*

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nia Fish and Game has kindly relaxed his normally strict protocol with respect to design and statistical basis in the interest of presenting a paper that answers many questions while motivating professional and student alike toward further research. It is my pleasure to have been a close friend and colleague of the author since the days of Paul R. Needham in Berkeley and to have participated at intervals in this seemingly endless study. "Sam" Reimers' experiential background qualifies him as an expert unique in his field. Read his paper thoughtfully, bearing in mind the largely unplanned and unpredictable progress as the life history proceeded far beyond any reasonable expectation. Consider that if a comparable study were to be started today, its investigations could not be completed until the year 2003.

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INTRODUCTION

Unusual longevity in fishes is discovered by recapture of individuals marked at a known age, by maintenance of known-age specimens in captivity, or by counting annual growth rings on scales, otoliths, etc. Rarely, knowledge of a long lifespan may be expanded through periodic observations on a discrete population living in natural circumstances. In this instance, members of a generation of brook trout (*Salvelinus fontinalis*) that originated in a hatchery in 1950 were observed through 23 years (1951–1974) in rock-bound, high-alpine Bunny Lake of the Sierra Nevada in eastern California. Ages to 19 years were known by recoveries, from 1952 to 1969, of marked individuals. Later ages of 20 and 24 years were verified on otoliths taken from fish in 1970 and 1974.

An earlier account (Reimers 1958) described post-introduction growth, apparent reproductive failure, and impact of an initial fish population upon the invertebrate food supply. At age 7 years, these trout had already equalled or exceeded the commonly known lifespan of the species as indicated in contemporary literature. An additional 17 years of life could not have been imagined and most of the subsequent activity consisted of repetitive efforts to add biological detail to the developing chronology. As time passed, mortality steadily reduced the numbers of fish available for collection and study. By 1973, no more than a dozen trout were present in the lake; in 1974, the end of the long cycle was signalled when only one aged specimen could be found during a 2-day search.

In addition to the evidence of record age, this report provides sequential data on growth and food relationships for most of the life history, presents the results of laboratory trials which demonstrated some remaining potential for reproduction and renewed growth after long periods of repression by low temperatures and insufficient food, and proposes by evidence of histological comparisons with young fish that physiological degeneration was so slow and slight as to be essentially undetectable in the advance of chronological age. The emphasis is on later life (ages 12 to 24 years) although the earlier work is reviewed briefly for descriptions of the environment and to provide continuity in an exceptionally long succession of observations. Fish growth, depreciation of the food supply,

and shrinkage of the trout population were progressively interrelated and are taken up together in order of apparent changes, rather than separately. Information on normal ages and the verification of 24 years of life follow the body of data concerned with biology and life history.

MATERIALS AND METHODS

The trout used in this study were provided by the California Department of Fish and Game and were stocked in 1951 following surveys of the lake's bathymetry, physical and chemical characteristics, and biota. These data and later measurements of fish age and growth, food, and invertebrate abundance up to 1957 were described previously (Reimers, op. cit.) with mention of the methods used.

Similar field methods were employed in the later phase of the investigation. Water temperatures were occasionally checked with either a Foxboro resistance-bridge thermometer or a thermistor, both equipped with calibrated long-line probes. Oxygen concentrations were determined by the Winkler method, with correction for elevation. Benthic invertebrates were sampled with a 6-inch × 6-inch Ekman dredge operated from a rubber raft; samples were washed and separated from a soil sieve and quantified volumetrically by water displacement as described by Welch (1948). Larger aquatic insects, not found in dredged samples, were sought by examining rocks and by using rakes or hand nets in shallow water. Plankton searches were made with a Wisconsin-type straining net in both vertical and horizontal hauls. Trout were collected by fishing with small artificial flies, accumulated in portable live-boxes, and either killed or lightly anesthetized with solutions of chlorobutanol or tricaine methanesulfonate (MS-222) depending on the use planned. Fish were measured to the nearest millimeter on a graduated board and weighed to the nearest two-tenths of a gram on a Welch triple-beam balance or a Torsion projection balance. The contents of trout stomachs were analyzed both volumetrically and numerically when possible; in some years there was not enough food for displacement measurements. Food organisms from benthic samples and stomachs were identified by specialists as necessary.

Transfers of trout to the laboratory were made in canvas buckets equipped with battery-powered aerators if hand-carried, or in 5-gallon stainless steel cans if pack animals were available. Water was changed frequently during the 3- to 4-hour trips and no immobilizing drugs were used. Fish in cultural experiments were held indoors in fiberglass tanks and troughs with continuously circulating stream water. The unheated water followed seasonal temperature variations, but was tempered to avoid summer surface-water extremes by its transit and storage in over 200 m of 20-cm underground pipe. External parasites were treated with formalin, and fungus was controlled with malachite green in low concentration. Artificial spawning of aged trout was conducted at the Hot Creek State Fish Hatchery with routinely used equipment, including a Heath incubator.

Dissections and gross examinations of organs were made with an illuminated magnifying lens or a low-power microscope. Surveys of sperm cell condition utilized a compound research microscope with oil immersion or phase contrast. Otoliths were located and collected via sectioning of crania and removal of brains, then cleaned with water and stored dry for later study. Samples of trout tissues for histological study were fixed and preserved in Bouin's fluid prior to

standard alcohol exchanges. Technical processing and evaluation of several hundred tissue specimens were beyond the capabilities of a field laboratory and this work was undertaken cooperatively by the well-staffed and superbly equipped Western Fish Nutrition Laboratory, U.S. Fish and Wildlife Service, at Cook, Washington. Paraffin embedding was standard in the preparations, but celloidin was used for a few ovarian samples. Hematoxylin and eosin stains in combination were used routinely; Mallory-azan and aldehyde-fuchsin were used in some preparations of glandular tissue. Most tissues studied were amply represented by serial or skip-serial sections in order to confirm observed features. Final analyses were derived from transcriptions of tape recordings made as the slides were studied.

THE ENVIRONMENT

Bunny Lake lies in a granitic cirque at an elevation of 3,322 m near the southwestern rim of the upper Convict Creek drainage, within the John Muir Wilderness (Inyo National Forest), about 16 km southeast of Mammoth Mountain in Mono County, California. The lake is almost unknown to anglers because of the proximity of several larger lakes at lower elevations. It is reached via 16 km of trail and a 1-km climb over a series of rock benches and persistent snowfields. Physical, chemical, and biological features were described in a previous report (Reimers, op. cit.) which may be consulted for details and photographs. Only a brief commentary will be given here to affirm a setting of extreme oligotrophy.

Typical of high glacial relicts, the lake has shores and bottom of bedrock, boulders, decomposed rock, and sand. It has a surface area of only 1.03 ha and a maximum depth of 7.5 m. The entire watermass is euphotic and fully transparent except when strong wind-mixing causes temporary turbidity. The annual water temperature range is approximately 14 C (0–14.5). Lowering air temperatures and wind-mixing easily adjust water temperatures downward during summer and fall; mean temperature reductions of 5 or 6 degrees are possible within a week after a sudden change of weather. The duration of ice cover averages somewhat over 8 months per year; the lake is frozen over by the end of October and substantial remnants of previous winter ice are sometimes present in mid-July. Mean water temperatures below 4 C are certain for nearly three-quarters of each year, including part of the open-water season; temperatures of 1 to 3 C prevail under the ice. On an annual basis, this environment is clearly one of unusual cold when compared with nearly all other types of brook trout water in the temperate zone.

The water is soft (pH 5.8–6.3; total hardness as $CaCO_3$ 0.9–6.0) and has an overabundance of dissolved oxygen at all depths. Total dissolved solids from mid-depth water samples were 8.2 mg/l before the introduction of fish and 5.6 mg/l 2 years after; of 17 constituents, all but silica (SiO_2), bicarbonate (HCO_3), and sulfate (SO_4) of the earlier sample were determined as less than 1 mg/l. Dissolved organic matter was estimated by loss on ignition at 0.2 mg/l. These concentrations have been represented as among the lowest in available records for natural waters (Reid 1961); they express eloquently the near absence of edaphic influence upon lake water composition in this type of drainage.

The flora and fauna of such a stark environment are limited in diversity by problems of colonization or adaptability and in density by the lack of a produc-

tive nutrient base. Excepting bacteria and other minute forms, Bunny Lake's sparse aquatic plant life consists entirely of algae dominated by diatoms (Table 1). No algal blooms were observed and none are thought possible; some genera could be represented only after extensive scanning of films scraped from rocks. Aquatic macroinvertebrates, the primary food of trout, were less than moderately abundant initially and suffered drastic reductions with overutilization; identification was made, to genus and species when possible, for those invertebrates present before the introduction of fish and in later years (Table 2).

TABLE 1. Algae of Bunny Lake.

Bacillariophyceae (diatoms)	Chlorophyceae (green algae)
Navicula	*Zygnema*
Pinnularia	*Spirogyra*
Fragilaria	*Mougeotia*
Cymbella	
Tabellaria	Cyanophyceae (blue-green algae)
Nitzschia	Nostocaceae—(1 species, unidentified)
Gomphonema	
Synedra	

TABLE 2. Aquatic Invertebrates of Bunny Lake, with Indications of the Effects of Overcropping by Trout.

NEMATODA (roundworms)	1 species, unidentified
ANNELIDA	
Oligochaeta (bristleworms)	*Edmondsonia montana*
MOLLUSCA	
Pelecypoda (fingernail clams)	*Pisidium* sp
ARTHROPODA	
Crustacea	
Cladocera (water fleas)	*Daphnia pulex* †
Copepoda (copepods)	*Diaptomus signicauda* †
Arachnoidea	
Hydracarina (water mites)	*Lebertia* sp †
Insecta	
Diptera, Tendipedidae (midges)	(*Genus* spp) *
Trichoptera, Limnephilidae (caddisflies)	*Hesperophylax* sp ‡
Coleoptera, Dytiscidae (beetles)	*Agabus tristis* ‡
	Hydroporus funestus †
Hemiptera, Corixidae (water boatmen)	*Cenocorixa kuiterti* ‡
Ephemeroptera, Baetidae (mayflies)	*Ameletus* sp †

* Identification not possible without adults reared in association with immatures.
† Absent from all samples after 1952.
‡ Absent from all samples 1953–1964; reappeared in food, 1965–1966.

TROUT POPULATION HISTORY

Review: 1951–1957

In August 1951, approximately 1,800 young brook trout were placed in previously fishless Bunny Lake for a short-term study of their ecology and population development in this mineral-poor water. Ironically, one objective of the study was to determine if the lifespan of brook trout in lakes of the region was indeed limited to 3 or 4 years, as commonly believed. Hatchery-reared from eggs of wild fish, the trout averaged 6.6 cm when stocked at 9 months of age (Table 3); as

the trout were nearing 1 year old when introduced, ages in years correspond to final digits of the years listed (*e.g.*, 1951 = 1; 1965 = 15).

TABLE 3. Growth of Brook Trout in Bunny Lake as Indicated by Fish Lengths in Various Years.

Year	*Number of fish sampled*	*Mean total length (cm)*	*Growth per year (cm)**
1951	100	6.6	–
1952	76	12.0	5.4
1953	33	13.3	1.3
1954	46	14.9	1.6
1955	27	15.2	0.3
1956	–	–	–
1957	37	16.3	0.6
1958–61	–	–	–
1962	16	19.3	0.6
1963	14	19.2	–
1964	8	21.6	1.2
1965	6	23.6	2.0
1966	–	–	–
1967	3	24.1	0.2
1968	3	23.6	–
1969	3	24.9	0.4
1970	10	25.2	0.3
1971	–	–	–
1972	3	29.5†	–
1973	1	24.0	–
1974	1	23.8	–

* Mean annual increment for interval since last measurement.
† Sample included larger second-generation trout and does not estimate growth of 22-year-olds, see text. Observations, 1966–1974

In their first year the trout tripled in weight and increased over 80% in length, achieving an essentially normal pattern of development from fingerling to subadult form. The 5.4-cm growth increment was not quite comparable to the 6.9-cm average increment for brook trout in 7 larger lakes of the upper Convict Creek basin (Reimers, Maciolek, and Pister 1955). Also in the first year, intensive foraging virtually eliminated all but three kinds of benthic invertebrates as well as the zooplankters *Daphnia* and *Diaptomus* (Table 2). With the extreme reduction of food, fish growth approached a standstill. The average *sum* of growth for the 5-year period from the summer of 1952 to the summer of 1957 was 4.3 cm; average gains in weight were similarly slight (106% in 5 years) and the condition factor, K ($= 100 \times$ weight in grams/(length in cm)^3), declined from 0.870 to 0.779, marking progressive loss of flesh. By 1957, the summer standing crop of benthos had dropped by more than 77% (5.73 to 1.29 cm^3/m^2). Sampling of the trout diet in 1952 and succeeding years indicated a continuing low-level subsistence almost exclusively on immature midges, with slight support from mollusks and airborne insects.

No evidence of spawning activities or reproduction was found during this period. Examination of gonads in August 1954 showed apparently normal development of both sexes approaching first maturity; however, later in the year no ripe fish were found and signs of regression (resorbing mature ova, lifeless immature cells, and vascularized, depleted testes) were noted. A similar pattern

of autumn sexual development was observed through 1957. Several factors worked against propagation: typical spawning locations, in areas of inflowing or upwelling water, were absent; nutrition was severely limited; generative development was retarded; and, supposing that spawning did somehow occur, there seems a strong likelihood that any young exposed to several hundred ravenous trout would be as vulnerable as the invertebrates had been.

Judged with reference to a summary of the then-current literature (Carlander 1953) in which reports of brook trout older than 5 years were rare, the Bunny Lake fish were advanced in age at 7 years. Emaciated and barely growing, they appeared to face certain starvation in a badly depleted food environment. It was not difficult to conclude that decline of the population was at hand.

Observations: 1958–1965

Cursory inspections of the lake and the trout were at first continued mainly to satisfy curiosity as to immediate survival status. Limited sampling was resumed in 1962, by which time a sudden failure of the population seemed unlikely. Growth for the 5-year interval 1957–1962, estimated by the difference in mean total length of trout in samples from the end years, amounted to only 3.0 cm (16.3–19.3) and the average annual increment of 0.6 cm was the same as for the preceding span (Table 3). The activity, propensity for feeding, and condition of the fish appeared unchanged. Without an acceptable estimate of the number of fish remaining in 1962, but with the knowledge that no radical reduction had been discernible in any one of several years, it may only be suggested that such continued slight growth was probably associated with the maintenance of a population large enough to hold food availability at a minimum.

Growth for the period 1962–1965 was again estimated by total lengths of trout and average annual increments (Table 3). The sample for 1963 showed no growth since the previous summer. However, increases for 1964 and 1965 were significantly greater than for any yearly interval since 1954; comparison reveals that the indicated growth for these 2 years combined (4.4 cm) was equivalent to the total of the preceding 9 years (1954–1963: 4.3 cm). Corresponding gains in weight raised condition factors to values representative of normal nutrition (1964: 1.150; 1965: 1.005) after several years of gauntness as typified by the factor 0.779 for 1957 and as appraised visually in later years.

After 1963, the killing of trout for food analysis and other measurements was held to small numbers in the interest of keeping some survivors to the greatest attainable age. This minimal sampling was not considered a limitation on the coarse evaluation of feeding, as the diet was predominantly midges in all years and the variety of other prey was small (Table 4). Flying insects were sometimes available but were of minor importance; only in a few stomachs containing ants could organisms other than midges be regarded as more than occasional items. Some measure of improved forage was implied by larger volumes of food in stomachs to represent the growing seasons of 1963–1965. Of special interest is the occurrence in 1965 of small numbers of aquatic beetle larvae, caddis larvae, and water boatmen, not seen since 1952 and thought to be lost from the food fauna.

Together with improved growth and body condition, the increased food consumption suggests a change in the availability of food per fish beginning some time in 1962 or early 1963. The reason for such a change is not evident

in results of limited lake-bottom dredging to represent these summers (Table 5); though few in number and comprised largely of minute organisms that are poorly suited to complete sorting or accurate quantification in the field, the samples roughly indicated a food base that continued to border on barrenness. Lacking confirmation by an adequate census, the upward trend in growth may be related only logically and observationally to reduced numbers of trout and enhanced feeding opportunities. A July 1963 estimate of fewer than 150 fish was based on an average count of 95 during calm-water periods of active feeding. By 1965, according to counts of active fish over many hours, there remained no more than one-third of the trout in evidence 2 years earlier.

TABLE 4. Summer and Autumn Food of Brook Trout in Bunny Lake, 1952–1965.

Date	*Number of trout*	*Mean volume of stomach contents (cm³)*	*Percent Tendipedidae (by number)*	*Other organisms eaten**
8/52	20	0.13	95	M, Hym, Hyd, C (l & a) †
8/57	20	0.17	98	M, Hym, C (a)
9/59	5	0.43	96	M, Hym, N, Ho, C (a)
9/62	26	0.19	99	Hym, He, C (a)
8/63	5	0.65	95	
9/63	5	1.78	97	Hym, He, C (a), Ho, A
10/63	5	0.24	95	
10/65	6	1.75	99	He,‡ C (l),‡ T (l) ‡

* A, Arachnida; C, Coleoptera; He, Heteroptera, Ho, Homoptera; Hyd, Hydracarina; Hym, Hymenoptera; M, Mollusca; N, Nematoda; T, Trichoptera.

† (l), larvae; (a), adults.

‡ Aquatic species; first reappearance since 1952 (C and He entries for 1957, 1959, 1962, and 1963 were non-aquatic adults).

TABLE 5. Benthos of Bunny Lake in 1962 and 1963, as Sampled by the Quarter-Square-Foot Ekman dredge.

Date	*Number of samples*	*Depth range (m)*	*Average volume* per sample*	*Average number per sample*			
				Nematoda	*Annelida*	*Mollusca*	*Diptera*
8/62	5	0.6–5.8	0.05	–	4.0	4.0	11.0
9/63	8	0.6–6.4	Trace †	0.6	1.6	–	2.9

* Volumes in cm^3

† Volumes too small for measurement.

Observations: 1966–1974

During this interval, scarcity of fish and the presumption of their imminent disappearance discouraged planning for more ecological study of the aged trout. A few were sought nearly every summer or fall for the record and food habits were monitored as possible. The impoverished condition of the invertebrate community left little opportunity for its further investigation; in attempted sampling (July 1966), plankton hauls yielded only algal material and dredging recovered only buried worms, clams, and midge larvae as in 1963. Although fish growth had again ceased and little additional information was anticipated, two remarkable developments could be followed.

In 1966, caddisfly larvae (*Hesperophylax* sp) appeared in the food of some trout, following the preceding year's tenuous indication that these and the origi-

nally common aquatic beetles might return to some dietary importance with a lower level of predation. October food of six trout averaged 1.1 cm^3 in volume, with approximately 70% caddis larvae and the remainder in immature midges, ants, and small flying insects of terrestrial origin. Similar feeding was noted in July 1968, the last examination of record, when four stomachs contained caddis larvae and debris, some flying insects, and relatively few midges. Since amounts per feeding had not shown an increase, such a change in composition could not be regarded as important to the surviving trout. However, the mere availability of this larger aquatic insect after an apparent absence of 14 years was seen as a sign of faunal recovery and as further evidence that the fish population was being reduced to a remnant.

In October 1966, years after all thoughts of natural reproduction had been forgotten, prespawning interaction and nest-digging were observed for the first time. Only four trout were active in one small area and no similar activities or other disturbed lake bottom were seen, then or later. No young were discovered in 1967 and this behavior was dismissed as ineffectual; its consequences were not learned until July 1968, when a few young trout of two sizes (estimated at 4–5 and 10–12 cm) were seen. Because the sizes were appropriate and there was no possibility that others could have introduced the smaller class before July, these fish were judged to be the products of very limited spawning in 1966 and 1967. The young trout were not seen again as juveniles but appeared to make up the growth sample for 1972, in which the three trout taken were 4 to 5 cm longer than those from prior or later years (Table 3) and almost 3 times as heavy (average 305 g; $K = 1.190$). The small, fast-growing second generation was finally verified by an examination of otoliths in 1974.

From 1966 onward, observations of behavior and physical condition gave some subjective indications that old age was at last overtaking less-favored survivors of the original population. Slow, aimless swimming and lack of wariness in daylight hours were more commonly noticed. Impairment of optic photoreception was shown by occurrences of darkly pigmented individuals over light colored substrates. The eyes of captured dark fish had clouded or opaque lenses. Emaciated old trout, with or without damaged eyes, were prevalent among the few that remained.

LABORATORY STUDIES

Culture and Growth

Several small lots of trout were hand-carried to the laboratory for tests of growth in what were assumed to be more favorable conditions of higher water temperatures and adequate food. The stream water used for culture was nearly 1,130 m lower than Bunny Lake and fluctuated over a larger annual range in temperature (2–18 C) with about 3 months longer per year in the upper half of the range. All transfers were made in cold, oxygenated water, with great care taken to minimize both handling injuries and thermal shock, yet many fish expired after a few weeks in captivity. Feeding trout, as well as non-feeders, weakened and died, usually with external fungus as the only gross symptom of an underlying debility. Circulatory failure was suggested as the final stage in a common decline which included several days of lassitude and disorientation followed by tremors, discoloration, and rigor that spread from the tail forward

until only gill motion remained. Except on two occasions, when bacterial infections overcame entire groups, the real cause of these deaths was not ascertained.

Because little growth could be expected in near-freezing water during the winter following transfer, any assessment of the capacity to accelerate growth after prolonged stunting required substantial feeding over the next spring and early summer as a minimum. The majority of the trout remained excessively wild and ate nothing. Most of those that did feed would accept only live food. Some non-feeders endured starvation through winter months, while most feeders deteriorated in spite of improved nourishment. The seemingly simple combination of continued health and inclination to feed occurred in only 12 of 69 trout from over a dozen growth trials attempted between 1962 and 1973. Information on individual growth came from just two fish, each one of which was the lone survivor of its group. The female survivor of a group that was transferred in October 1962 fed freely on live amphipods and nymphs, growing for 20 months at rates that varied from 0.2 to 1.4 cm per month depending on water temperature and appetite. Growth for the entire period was 1.6-fold in length (18.5 to 29.8 cm) and 5.3-fold in weight (64 to 336 g). In comparison to the 12th-year specimen, an 18-year-old male that was maintained in good health on similar foods gained relatively little (1.1-fold in length and 1.3-fold in weight) from October 1968 to October 1969.

Most other trials were less informative, primarily because of inability to maintain fish over significant periods or even to bring them to stable condition; some examples follow. In 1963, all 23 fish of transfers made in August and September died within 18 and 28 days, respectively; but 9 out of 10 trout from an October transfer, feeding on live earthworms and frozen brine shrimp, survived for a year with an average gain of 1.2-fold in length (19.2 to 23.8 cm) and 2-fold in weight (94 to 189 g). All 10 fish of an October 1964 transfer died within 14 days; in these, fungus rapidly invaded bite wounds of frequent agonistic encounters and bacterial infection was evident in later mortalities. Of 3 trout transferred in September 1973, two that were later determined to be aged fish died within 2 weeks. A third specimen, after discharging about 600 eggs in October, fed well and survived for 9 more months with gains of 2 cm and 43 g; this fish was then found to have been a second-generation 8-year-old.

Although there could be no critical comparisons of a few individuals over different time periods, particularly when temperature and rate of feeding were not controlled or adequately monitored, the trials did confirm that growth of severely stunted brook trout could resume at ages 12 to 18 years. Also, there was a suggestion that the capacity to improve growth diminished with increasing age.

Experimental Breeding

A single opportunity to test fertility of the trout at an advanced age occurred in November 1964, when one female and two male survivors of the October 1963 transfer appeared to be in condition for artificial spawning. The 14-year-old female produced about 150 undersized but evidently ripe eggs. Roughly half of these were mixed with spermatic fluid of a Bunny Lake male and the other half with fluid of a ripe male from the Mt. Whitney State Fish Hatchery brood stock. At the same time, a Whitney female was spawned and about the same number of its eggs were divided and mixed with sperm from the Whitney and Bunny Lake males. Whitney X Whitney was a control to establish normal potency of

sex cells in the 3-year-old brood fish under the test conditions. The 4 tests were held separately in an incubator at 13 C with variable results (Table 6).

TABLE 6. Fertility of 14-year-old Bunny Lake Brook Trout, as Estimated by Artificial Spawning and Incubation.

Test (male X female)	*Approximate fertilization (percent)*	*Approximate hatch (percent)*
1. Bunny X Bunny	40	5
2. Whitney X Bunny	50	40
3. Bunny X Whitney	30	10
4. Whitney X Whitney	95	80

In Test 1, though 40% of some 75 eggs were fertilized, only two developed eyes and only one hatched completely; the others formed defective embryos which remained statically alive for just a few days. Tests 2 and 3 seemed to imply somewhat greater potency of cells in the aged female than in the aged males. However, it was also clear from Tests 2 and 4 that fertility of the Bunny Lake female was far below standard. Post-hatching developments followed the expected gradient: Test 1 produced no viable larvae; Tests 2 and 3 produced only a few swim-up fry after heavy mortality that was due in part to 15 and 20% incidences of cripples (scoliotic, coiled, 2-headed); Test 4 produced a near-normal swim-up.

Dissections of mature ovaries from other 14-year-olds, moribund in October, revealed fully developed ova of about two-thirds normal size, with many dead. Microscopic examination of testes and spermatic fluid mixed with water found minimal, lobular development of germinal areas and few motile spermatozoa. It seems probable that both age and malnutrition influenced the low fertility and developmental aberrations observed. Materials were limited and these breeding trials were necessarily crude; they suggested only that some old trout might be able to spawn naturally if granted a sustained improvement in nutrition.

Histological Surveys

While most pertinent literature had given little encouragement for the demonstration of aging changes in structure and function of fish tissues and organs, one series of studies (Robertson and Wexler 1959, 1960, 1962; Robertson, Wexler, and Miller 1961) clearly pointed to such changes in spawning Pacific salmon (*Oncorhynchus* spp) which deteriorate rapidly and die on completion of the single reproductive cycle. It was supposed that comparative histology would permit a diagnosis of at least some aspects of senescence in the trout of Bunny Lake.

A random selection of tissues from 14 fish was processed in 1962 to obtain a broad view of the condition of 12-year-old trout. Cumulative, age-related effects (calcification in basal areas of gill filaments with beginning ossification of branchial-arch cartilage, and deposits of melanistic pigment in kidney cells) were noted in some fish but no marked departures from normal were seen in other visceral and glandular tissues. The gonads of these summer-caught trout were too immature for an appraisal of reproductive development.

In 1963, slides of a full range of serially sectioned tissues (eye, brain, gill, heart, skin and muscle, inter-renal, hemopoietic and urinary kidney, liver, spleen, esophagus and stomach, pyloric caeca and pancreas, anterior intestine, gonad,

pituitary, thyroid, and thymus when present) were prepared from 13-year-olds captured in late autumn and from 1- to 4-year-old brook trout caught in a neighboring lake. No clear evidence of senile degeneration was found in comparisons of these materials, although several deficiencies were apparent in the old trout. The aforementioned calcification and pigmentation were prevalent; atrophic skeletal muscle fibers and lowered profiles in epithelial cells were occasional; liver cells were starved, as opposed to abundantly vacuolated; some kidneys had noticeably undersized glomeruli, possibly indicative of waning function; the gonads of most maturing specimens had one or more of various dystrophies such as gross deformities of testes (Figure 1), isolated spermathecal cysts, sperm stasis at the spermatid stage, tailless spermatozoa, ovaries filled with resorbing ova and shriveled oocytes, or ovarian connective-tissue barriers to the release of eggs. Of these variations from the normals of young trout, only the first may be considered unequivocally age-related; the others could as easily be the result of marginal nutrition. The morphology and distinctive staining properties of secretory cells in pituitary, thyroid, inter-renal, and pancreatic tissues indicated normal or near-normal function in old trout. The tissues of hemopoietic and cardiovascular systems were essentially unchanged with age.

FIGURE 1. Testis of 13-year-old Bunny Lake brook trout, showing general underdevelopment with lobular deformity. *Photograph by U.S. Fish and Wildlife Service, November 1963.*

In 1965, surveys were completed on the gonads of one female and four male 14-year-olds that had been fed, developed to sexual maturity in laboratory tanks (October 1963 to October 1964), and killed when moribund. Whereas the female exhibited evidences of general ovarian regression, as had others taken directly from the lake, all males appeared closer to reproductive effectiveness with complete development of sperm cell stages in most areas examined. With

but a single female represented it is superficial to suggest that improved nutrition benefited males discriminately, but the outcome did imply that malnutrition could have produced some of the previously observed anomalies in germinal tissues.

Another full-range comparison of tissues from 18-year-old trout with those of 2- to 4-year-old brook trout taken from Cloverleaf Lake, a more productive water lower in the same drainage, was completed in 1969. Only three aged trout were available for this purpose; four of the younger trout were used as the standard of normal condition. As in 13-year-old trout, two definitely age-related but apparently harmless conditions were prevalent in the old fish, namely, heavy black pigmentation (lipofuscin, up to three times normal) in cells of kidneys and some other internal organs, and calcification of normally hyaline branchial elements. As before, scant production of largely atypical germinal cells, slight indication of skeletal muscle atrophy, and evidence of reduced energy storage in liver tissue were noted; as before, such effects could be attributed to the nutritional status as well as to aging change. In addition, the following conditions were found in old trout: pituitary and thyroid sizes and cell types were normal; there was slight hyperplasia in some thyroid-follicle areas, indicating activity and probable general absence of hypothyroidism if nothing else; one spleen was unusually dense with heavy stroma, appearing fibrotic in general aspect, but the splenic tissue of other specimens was normal; the head-kidney sections showed normal inter-renal tissue with cortex of reduced extent; in urinary kidneys some glomerular basement membranes were abnormally thick; one pancreas gave a hint of possible senescent change with arterial sclerosis and degenerating islets, but pancreatic tissue of two other aged fish was normal in both islet and acinar components. Other comparisons of gastrointestinal, nervous, and vascular tissues failed to show appreciable differences between old and young trout.

In most respects, conclusions of this final study were not different from those of earlier examinations. Judged against young brook trout that were invariably normal and healthy, the 18-year-olds were still remarkably well preserved from a histological standpoint, showing few signs of deterioration and no evidence of impending physiological breakdown. There were no manifestations of the hyperpituitarism, hyperadrenocorticism, and hypothyroidism which result in the overwhelming hormonal imbalance known to cause rapid aging decline in Pacific salmon. Considering the slow pace of the subtle alterations observed, it seems doubtful that larger samples or opportunities to examine naturally moribund fish would have changed the findings.

DETERMINATION OF AGE

In 1952, 347 (about one-fifth) of the trout introduced the previous summer were caught, marked by amputation of the left pelvic fin, and returned to the lake. In most subsequent years through 1969, one or more marked fish were collected in the course of sampling; these marks established continuity of the stocked generation for laboratory records but did not provide material evidence of attained age. As the scale method had proved to be incapable of aging these fish beyond the third year (Reimers 1958), the alternative was an attempt to find the record of years on otoliths.

Six pairs of sagittae (largest and most useful of three otoliths in each ear capsule) were dissected from trout of the 1970 sample and sent to a recognized

authority for preparation, study, and photography of suitable material. After several weeks of clearing in anise oil, otoliths from all fish of this collection showed 20 annual rings when examined in reflected light and the best of these was photographed entire on black glass (Figure 2). The light (opaque) bands represent principal growth of the year, while the dark (translucent) rings indicate yearly checks in growth of the animal and are referred to as "winter bands" by analogy with similar indications on scales. In the figure, a count should begin at the origin of growth in the center and proceed upward to the elongated tip. The light, central field is the zone of first-year development; counting from its outer edge, one may distinguish 19 additional opaque bands without difficulty.

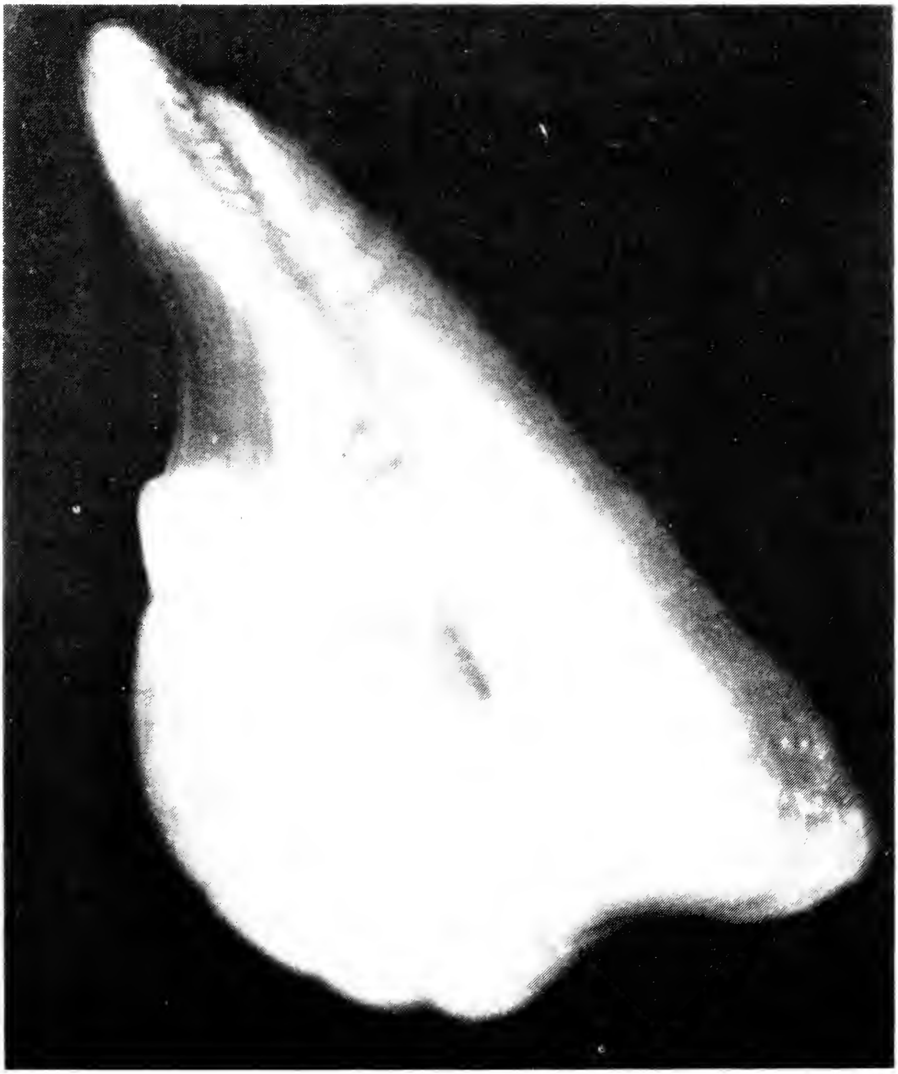

FIGURE 2. Intact otolith of 20-year-old Bunny Lake brook trout, greatly enlarged. *Photograph by Jack M. Schott, California Department of Fish and Game, April 1971.*

In 1973, two specimens were otolith-aged at 23 years. These had been transferred to tanks and had died within 2 weeks of capture, but a third, significantly larger fish survived to develop sexually, release its eggs, and grow from 29.2 to 31.2 cm, with over 40% weight increase through the following winter and spring. Examination of otoliths from this large individual in 1974 indicated an age of 8 years, putting the origin at 1966 when spawning activities were noted and providing evidence of an incredibly late second generation in the lake.

The otoliths of the single fish recovered in 1974 were not of sufficient quality to be examined or photographed intact. Excessive thickening and some deformation had resulted in enough surface irregularity to prevent a comprehensive focus and many of the bands were poorly defined. Therefore, a wafer was sliced from a transverse cross-section through the center and then broken to provide a single "radius" with the best obtainable transparency and flatness. On such a shorter dimension (wafer diameter = 0.97 mm) the outer bands are in closer proximity but have the same sequential arrangment as on the long axis. All light and dark bands were distinguishable microscopically but lacked enough contrast to be differentiated in a photograph. To produce a useful demonstration it was necessary to accent and re-photograph an intermediate print for emphasis of translucent bands along the counting radius. Although some resolution was lost in the second negative and its enlarged print, most of the added arcs can be traced to their fainter extensions; with this artifice, one may count the 24 years as opaque (light) bands beginning with the central field at the lower right (Figure 3).

All of the otoliths used in the study are on file with the author. The ages ascertained with these materials may be verified in records of the Marine Resources Laboratory, California Department of Fish and Game, Long Beach, California.

DISCUSSION

Perhaps the most singular aspect of this life history was its duration, expressing a prodigious tenacity of life in a few stunted fish whose fortune might be considered good or bad depending on the point of view. A summary of some observed maximum ages for brook trout in several regions may aid an appreciation of the phenomenal longevity attained at Bunny Lake. From studies in Maine, Massachusetts, New Hampshire, Nova Scotia, Michigan, and Montana, Bridges (1958) listed only one group out of 14 with age as great as 7-plus years and only three collections with fish over age-group IV (in 5th year of life). A maximum age of 7 was recorded for brook trout in Maligne Lake, Alberta (Rawson 1941). McFadden (1961), surveying mountain lakes in Montana, found no individuals older than age-group VI. According to studies of the New York Conservation Department (Stone 1960), the greatest ages on record were seven growing seasons for wild brook trout and five seasons for hatchery brook trout. Among 235 anadromous brook trout sampled in Nova Scotia, the highest Wilder (1952) noted was one fish of age group VI.

The foregoing records show consistency in observed maximum age through much of the natural and introduced ranges of brook trout in North America. In general, the various waters that may be called ordinary in terms of temperature and nutrients support life histories estimated at 4 to 6 years; slightly older trout are found infrequently. Extraordinary, apparently, are many elevated lakes of

western mountain areas where trout are inhibited in growth by combinations of population pressure (usually resulting from overstocking and underfishing) and insufficiencies in one or more of the primary trophic influences (thermal, radiational, geochemical) which determine productivity. Although difficulties with stunted brook trout and interest in remedial management continue to prompt studies of such lakes (*e.g.*, Rabe (1968) on comparative fish growth and Walters and Vincent (1973) on invertebrate population dynamics following eradication of trout), only a few marked brook trout have been observed long enough to establish unusual known age. Wales (1958) noted an age of 10 years in survivors of a marked group from Castle Lake, California; at the time, no older brook trout were known. Nelson (1964) reported on marked returns to age 12 years from Sugarbowl Lake, Colorado, at an elevation of 3,289 m, a lake in which environmental conditions were much like those in Bunny Lake.

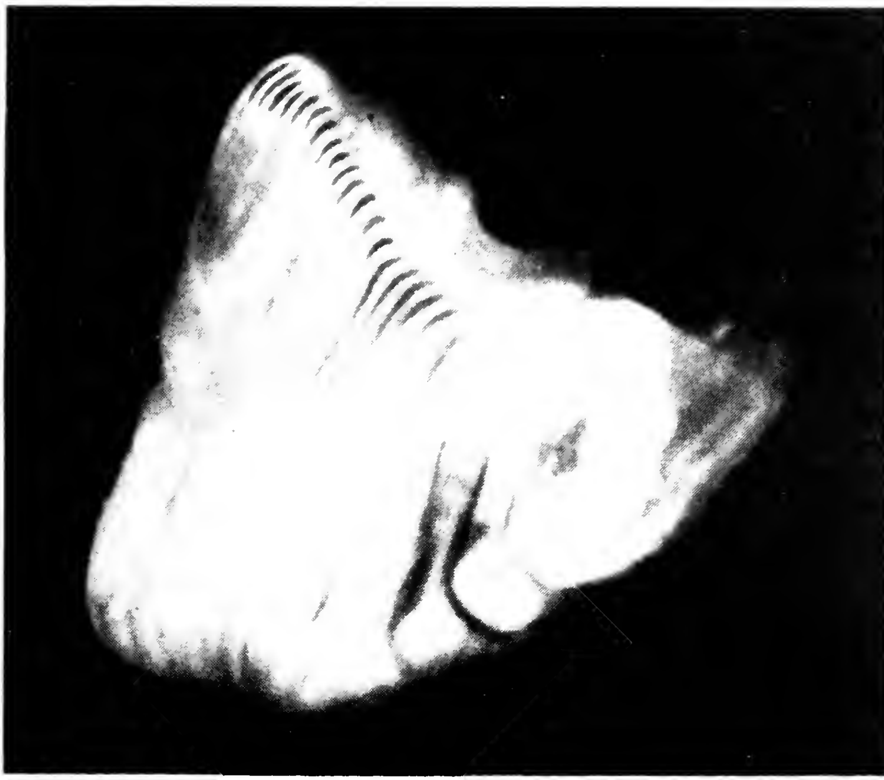

FIGURE 3. Wafer of cross-sectional semidiameter from otolith of 24-year-old Bunny Lake brook trout, greatly enlarged. *Photograph by Jack M. Schott, California Department of Fish and Game, November 1974.*

Comparisons of longevity are complicated by the interaction of species potential and environmental factors. Removal of fish has an effect in obscuring knowledge of natural limits on age; most of the records cited do not represent longevity, but only the greatest ages found in managed populations that were

characterized by low average age and scarcity or absence of old individuals as a result of turnover. In that connection, however, recorded maximum ages of trout sheltered in temperate aquaria (Breder 1936; Nigrelli 1959; Hinton 1962) were lower than most recorded from the managed populations. Although Bunny Lake could not have supported such an extended life history without the shelter from interference afforded by its remoteness, it is obvious that the observed longevity did not result merely from protection. All evidence indicates that the dominant factor in adding many years to the lives of the trout was severe retardation due to the early and unremitting shortage of dietary calories in a temperature regime that was more often conducive to torpor than to activity. This conclusion is consistent with results of a line of gerontologic experiments (*e.g.*, MacArthur and Baillie 1929*a*, 1929*b*; McCay, Crowell, and Maynard 1935; McCay, Pope, and Lunsford 1956; Comfort 1963) in which reductions of caloric intake or environmental temperature slowed rates of growth and prolonged life in various short-lived animals.

Both nutritional status and aging influenced growth, health, and mortality of trout during the second half of the investigation and, while the pre-eminence of one factor or the other could sometimes be conjectured, it could never be firmly established. It seems likely that aging had more impact on accelerating mortality in the lake beginning about 1963, as earlier limitations on food almost certainly had extended rather than curtailed survival. Among the fish transferred to the laboratory, few could tolerate the change in living conditions but the assignment of age as the only cause of failure was made doubtful by the observation that wildness and incompatibility with confinement inhibited feeding and later survival to a considerable extent. The first successful natural reproduction occurred at the age of 16 years together with indications of some improvement in availability of food due to continued reduction of the trout population. Within 3 or 4 years of their emergence, a few second-generation trout demonstrated by superior growth and condition that food was no longer severely limiting; yet a steadily diminishing number of old fish of the parent generation remained stunted to extreme age (Table 3; Figure 4). This discrepancy implies that capacity for growth in the lake was later reduced by aging factors as well as by the low level of nourishment.

In the absence of water-quality problems, predation, and exposure to disease, failure of health due to age was surely the prime cause of death in the later years, but manifestations of decline were few, subclinical, and inconsistent in the fish sampled for examination of organs and tissues. Histological profiles showed more evidence of long-sustained good health than of pathology. In view of general observations that indicated weakness and deterioration with age, it must be concluded that gross histological values could not and did not adequately assess the aging changes experienced by these trout. Unlike spawning salmon, whose rapid aging degeneration results from marked physiological changes that are genetically programmed for short-term, one-time accommodation of the stresses of migration, the trout in Bunny Lake had no energy-multiplying mechanisms and no great demands for energy. They used minimal energy as dictated by the cold environment and they experienced a form of aging that proceeded almost imperceptibly.

In 1975, the only fish to be seen at the lake was a 34-cm male that was found dead under a snowbank (E. P. Pister, Associate Fishery Biologist, Department

of Fish and Game, pers. commun. 1975). The size of the specimen identified it without much doubt as one of the second generation, 8 or 9 years old. With the last few old trout gone, the population had finally run its course. It might now be asked whether the 24-year-old caught in 1974 was near a biological maximum age for the species. An affirmative answer is suggested by some evidence for the onset of old age and by the wasted appearance of late survivors; yet it is self-evident that there can be no innately determined chronological maximum when the length of life is so susceptible to extension by conditions that regulate the physiological age. Conceivably, the trout stocked in 1951 could have suffered an even more wretched existence than they did, with some of them living several years longer.

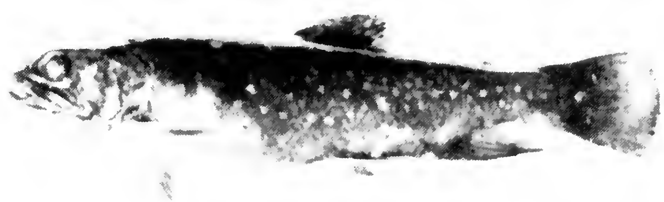

FIGURE 4. Bunny Lake brook trout at age 24 years. *Photograph by the author, October 1974.*

ACKNOWLEDGMENTS

During most of its course, this investigation was adjunct to a continuing program of trout research by the U.S. Fish and Wildlife Service at the Sierra Nevada Aquatic Research Laboratory, located between the Bunny Lake study area and the town of Bishop, California. Following the closure of the laboratory in 1973, the remaining work was completed without financial support but with some assistance from interested individuals.

Of the several people who participated or assisted, only three were aware of the final age to be attained by the trout. These were John E. Fitch and Jack M. Schott of the Marine Resources Laboratory, California Department of Fish and Game, to whom I extend sincere thanks for their interest and expertise in the verification of ages with otoliths as well as for technically difficult photographic evidence, and Edwin P. Pister, Region 5 Fishery Biologist of the same department, who maintained a constant interest throughout the investigation and aided both field work and correspondence.

For the supervision of many histological preparations and for his evaluation of most resulting materials, I especially thank Laurence M. Ashley, former Histopathologist at the Fish and Wildlife Service's now defunct Western Fish Nutrition Laboratory. The late O. H. Robertson, pioneer interpreter of aging physiology in salmon, also proffered advices on age-related conditions in some tissues.

Reed S. Nielson, Director of the Sierra Nevada Aquatic Research Laboratory until 1967, promoted early ecological studies at Bunny Lake and encouraged continued observation of the aging trout. More than a dozen other employees of the Fish and Wildlife Service assisted with collection of data and related field work at various times. Robert J. Toth, Fish Pathologist for the California Department of Fish and Game, advised on diseases and parasites in brook trout at the laboratory. Merle Reynolds, Manager of California's Hot Creek State Fish Hatchery in 1964, provided incubation space and technical aid in spawning and hatching experiments.

For other professional assistance in the identification of invertebrates, I am grateful to the following: W. W. Wirth, Diptera; R. K. Allen, Ephemeroptera; D. S. Flint, Trichoptera; P. J. Spangler, Coleoptera; J. L. Herring, Hemiptera; R. O. Brinkhurst, Oligochaeta; and I. M. Newell, Hydracarina.

REFERENCES

Bennett, G. W. 1937. The growth of the large mouthed black bass, *Huro salmoides*, in the waters of Wisconsin. Copeia 1937 (2): 104–118.

Breder, C. M., Jr. 1936. Long-lived fishes in the aquarium. Bull. New York Zool. Soc. 39 (3): 116–117.

Bridges, C. H. 1958. A compendium of the life history and ecology of the eastern brook trout, *Salvelinus fontinalis* (Mitchill). Mass. Div. of Fish. and Game, Fish. Bull., (23): 1–37.

Carlander, K. D. 1953. Handbook of freshwater fishery biology with the first supplement. Wm. C. Brown Co., Dubuque. 429 p.

Comfort, A. 1963. Effect of delayed and resumed growth on the longevity of a fish (*Lebistes reticulatus* Peters) in captivity. Gerontologia 8 (2): 150–155.

Domrose, R. J. 1963. Age and growth of brook trout, *Salvelinus fontinalis*, in Montana. Montana Acad. Sci., Proc., 23: 47–62.

Gerking, S. D. 1957. Evidence of aging in natural populations of fishes. Gerontologia 1 (5): 287–305.

Hinton, S. 1962. Longevity of fishes in captivity, as of September, 1956. Zoologica 47 (pt. 2): 105–116.

MacArthur, J. W., and W. H. T. Baillie. 1929*a*. Metabolic activity and duration of life. I. Influence of temperature on longevity in *Daphnia magna*. J. Exper. Zool. 53 (2): 221–242.

MacArthur, J. W., and W. H. T. Baillie. 1929*b*. Metabolic activity and duration of life. II. Metabolic rates and their relation to longevity in *Daphnia magna*. J. Exper. Zool. 53 (2): 243–268.

McCay, C. M., M. F. Crowell, and L. A. Maynard. 1935. The effect of retarded growth upon the length of life span and ultimate body size. J. Nutrition 10 (1): 63–79.

McCay, C. M., F. Pope, and W. Lunsford. 1956. Experimental prolongation of the life span. Pages 29–39 *in* R. L. Craig, ed. Problems of aging, 28th Grad. Sympos. New York Acad. Medicine, 1955. George Eliot Books, New York. 221 p.

McFadden, J. T. 1961. A population study of the brook trout, *Salvelinus fontinalis*. Wildl. Monogr. No. 7. 72 p.

Nelson, W. C. 1964. Rawah-McIntyre high lakes project. Pages 20–37 *in* Research in Colorado, Fish. Res. Div., Colo. Game, Fish, and Parks Dept., Ann. Rept. No. 1. 57 p.

Nigrelli, R. F. 1959. Longevity of fishes in captivity, with special reference to those kept in the New York Aquarium. Pages 212–226 *in* The lifespan of animals, CIBA Found. Colloquia on Aging, vol. 5. 324 p.

Rabe, F. W. 1968. Brook trout populations in high lakes. Northwest Science, 42 (1): 20–28.

Rawson, D. S. 1941. The eastern brook trout in the Maligne River System, Jasper National Park. Am. Fish. Soc. Trans., 70: 221–235.

Reid, G. K. 1961. Ecology of inland waters and estuaries. Reinhold Publ. Corp., New York. 375 p.

Reimers, N. 1958. Conditions of existence, growth, and longevity of brook trout in a small, high-altitude lake of the eastern Sierra Nevada. Calif. Fish Game 44 (4): 319–333.

Reimers, N., J. A. Maciolek, and E. P. Pister. 1955. Limnological study of the lakes in Convict Creek Basin, Mono County, California. U.S. Fish and Wildl. Serv., Fish. Bull. 56 (103): 437–503.

Robertson, O. H., and B. C. Wexler. 1959. Hyperplasia of the adrenal cortical tissue in Pacific salmon (genus *Oncorhynchus*) and rainbow trout (*Salmo gairdneri*) accompanying sexual maturation and spawning. Endocrinology 65 (2): 225–238.

——. 1960. Histological changes in the organs and tissues of migrating and spawning Pacific salmon (genus *Oncorhynchus*). Endocrinology 66 (2): 222–239.

——. 1962. Histological changes in the pituitary gland of the Pacific salmon (genus *Oncorhynchus*) accompanying sexual maturation and spawning. J. Morphol., 110 (2): 171–185.

Robertson, O. H., B. C. Wexler, and B. F. Miller. 1961. Degenerative changes in the cardiovascular system of the spawning Pacific salmon (*Oncorhynchus tshawytscha*). Circulation Res., 9 (4): 826–834.

Stone, U. B. 1960. How long do fish live? New York State Conservationist 15 (1). 9.

Wales, J. H. 1958. Castle Lake investigation—progress report for 1957. Calif. Dept. Fish and Game, Inland Fish Admin. Rept. 58-6.

Walters, C. J., and R. E. Vincent. 1973. Potential productivity of an alpine lake as indicated by removal and reintroduction of fish. Am. Fish. Soc., Trans., 102 (4). 675–697.

Welch, P. S. 1948. Limnological methods. Blakiston Co., Philadelphia. 381 p.

Wilder, D. G. 1952. A comparative study of anadromous and fresh-water populations of brook trout (*Salvelinus fontinalis* (Mitchill)). Can., Fish. Res. Bd., J., 9 (4): 169–203.

Calif. Fish and Game 65(4): 216–238 79

FIRE AND STREAM ECOLOGY IN SOME YELLOWSTONE LAKE TRIBUTARIES [1]

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This study attempted to clarify some effects of forest fires on streams in selected tributaries to Yellowstone Lake, Yellowstone National Park, in partial evaluation of the Park's natural burn fire management policy.

In a stream in a watershed burned 45 and 36 years ago (Passage Creek) some changes were found, when compared to a similar stream in an unburned adjacent watershed (Chipmunk Creek). Summer stream temperatures averaged about 1.5 C higher in Passage Creek. Streamflow showed a greater seasonal fluctuation and a higher water yield in Passage Creek. Water quality conditions in both streams were similar, but mineral export was greater in Passage Creek due to greater water yield. Aufwuchs accumulation on artificial substrates showed no significant difference between the two streams. Benthic sampling suggested a general increase in benthic macroinvertebrates in Passage Creek. The fry of Yellowstone cutthroat trout, *Salmo clarki lewisi*, appeared to emerge from the gravel earlier in Passage Creek than in Chipmunk Creek. Based on stream temperature differences, the difference in egg incubation time was calculated to be 4 days.

Two other streams were studied during and immediately after a fire burned their watersheds (Streams 173 and 174). No harmful effects were found. Concentrations of calcium, magnesium, potassium, chloride, sulfate, phosphate, and total organic carbon were raised somewhat during a rainstorm, apparently as a result of ash leached into surface runoff.

INTRODUCTION

According to the Second Law of Thermodynamics, organic material is an inherently unstable arrangement of matter. Organic material must eventually return, through disaggregation and release of energy, to the more stable inorganic state. The return to the inorganic state can be accomplished biologically, by decay and decomposition, or physically, by fire. In some terrestrial communities, the greater the accumulation of plant biomass, the greater is the probability of fire when conditions of wind and moisture are correct. Fire can be a natural, periodic occurrence.

The primary management philosophy in Yellowstone National Park is to maintain the Park in as natural a condition as possible, with human impact held to a minimum (U.S. National Park Service 1975). From about 1890 to 1972, fires were artificially suppressed throughout the Park; fire was prevented from assuming its full ecological role. In 1972, 138,000 ha of the Park were designated "natural fire zones." From 1972 to 1975, 19 lightning-caused fires totaling 340 ha were allowed to burn out, unsuppressed, in the natural fire zones. In February 1976, a natural fire management plan for the entire Park was adopted (U.S. National Park Service 1976). The plan calls for suppression of fires that are man-caused, or that threaten human life and property, cultural and historic resources, outside lands and resources, or endangered species. Other fires are generally allowed to burn. Fire control decisions are made on a fire-by-fire basis.

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The intent of the 1976 plan is to restore the natural influences of fire to the Park's plant and animal communities, in subscription to the Park's primary management philosophy. During the summer of 1976, under the 1976 fire management plan, a lightning-caused fire that burned 200 ha was allowed to burn out, unsuppressed, in the Continental Divide area of the Park.

To fully evaluate the 1976 Yellowstone Park fire management plan, the effects of fire on stream ecology in general, and on Yellowstone's fish populations in particular, should be known, whether the effects are beneficial, benign, or detrimental. This study attempted to identify and evaluate some of the long-term effects of fire on stream ecology by comparing a stream in an unburned watershed (Chipmunk Creek) with an otherwise similar stream (Passage Creek) in a watershed with burns 36 and 45 years old. In Chipmunk Creek and Passage Creek, effects on stream temperature, streamflow, water quality, benthic macroinvertebrates, stream productivity, and Yellowstone cutthroat trout, *Salmo clarki lewisi*, populations were examined. The hypotheses tested were:

1. Fire indirectly increases summertime stream temperatures by reducing stream shading through reduction in riparian vegetation.
2. Fire alters streamflow regimes as a result of changes in terrestrial vegetation and other watershed conditions.
3. Fire alters stream chemical water quality as a result of minerals contributed by ash and alteration of other watershed conditions.
4. Fire increases the biological productivity of streams.

This study also attempted to identify and evaluate some of the short-term effects of fire on streams by examining streams (Yellowstone Park Streams Nos. 173 and 174) during and immediately after the 1976 Continental Divide fire burned their watersheds. In Yellowstone Park Streams Nos. 173 and 174, effects on stream temperature, water quality, benthic macroinvertebrates, and Yellowstone cutthroat trout populations were examined, but in less detail than in Chipmunk Creek and Passage Creek. The hypotheses tested were:

1. During a fire, stream temperatures are increased.
2. During and immediately after a fire, stream chemical water quality is altered as a result of minerals contributed by ash.
3. The immediate temperature and water quality effects of fire may be lethal to aquatic life.

STUDY AREAS

Chipmunk Creek-Passage Creek Study Area

Chipmunk Creek and its main tributary, Passage Creek, are located in southeastern Yellowstone National Park, Wyoming. The creeks drain off the eastern slope of the Continental Divide into the South Arm of Yellowstone Lake (Figure 1). As used herein, "Chipmunk Creek" will refer to that portion of Chipmunk Creek above its confluence with Passage Creek. Above their confluence, Chipmunk Creek and Passage Creek are similar in gradient. Both streams are characterized by long, shallow riffles, and few pools. Chipmunk Creek drains an area of 39.3 km²; Passage Creek drains an area of 21.2 km².

The woody vegetation in the area is composed predominately of lodgepole pine, *Pinus contorta*; subalpine fir, *Abies lasiocarpa*; and Engelmann spruce,

Picea engelmannii; in the overstory. Grasses; sedge, *Carex*; and willow, *Salix*, are present along streambanks.

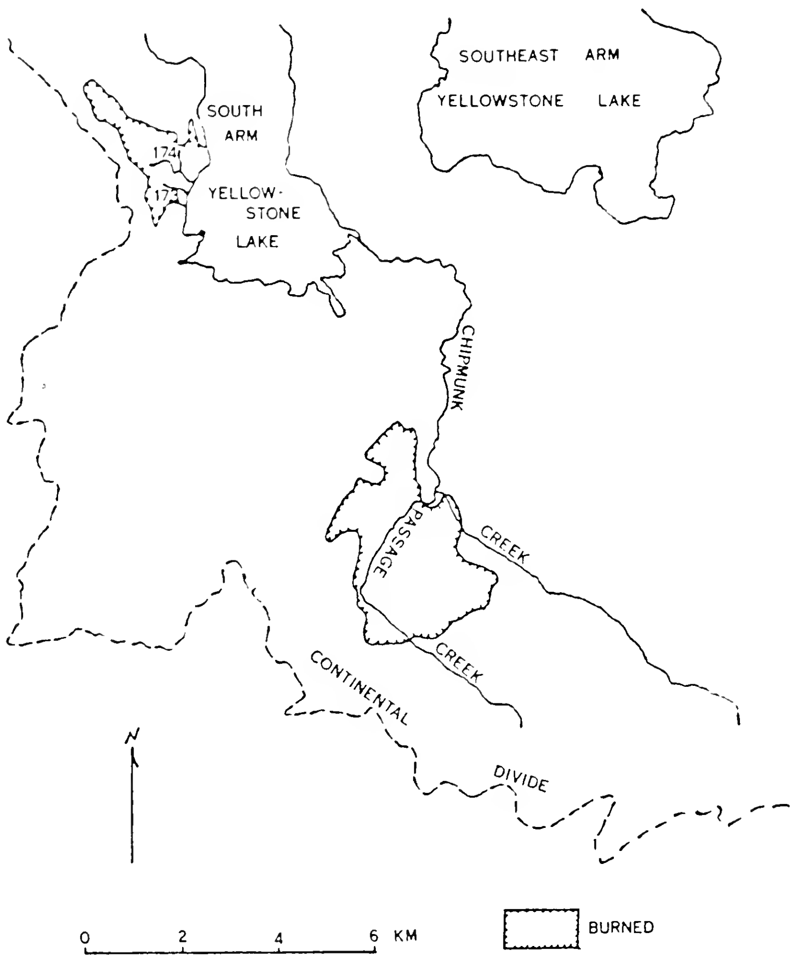

Figure 1. Chipmunk Creek, Passage Creek, and Streams Nos. 173 and 174, Yellowstone National Park, Wyoming. The locations of the 1931 and 1940 Chipmunk Creek burn, and of the 1976 Continental Divide burn, are shown.

In September 1931, a fire burned 506 ha near the confluence of Chipmunk Creek and Passage Creek (Figure 2). In June 1940, a fire burned 481 ha immediately south of the 1931 burn. Both fires were started by lightning and suppressed artificially. In both fires, the forest overstory was completely killed. In August 1953, a fire burned 49 ha in a location about 3 km east of the 1931 and 1940 burns.

The 1931 and 1940 burns, which have a common boundary, form a burned area of 987 ha. The burned area occupies about 20% of the Passage Creek watershed and borders both sides of Passage Creek for the lower 60% of the

length of the creek (Figure 2). The 1931 and 1940 burns also extend partially into the Chipmunk Creek watershed. Burned area, including the 1953 burn, occupies about 3% of the Chipmunk Creek watershed, and borders Chipmunk Creek along the lower 1 km of its length. For the purposes of this study, the burned areas in the Chipmunk Creek watershed are considered to be negligible with respect to possible effects on Chipmunk Creek.

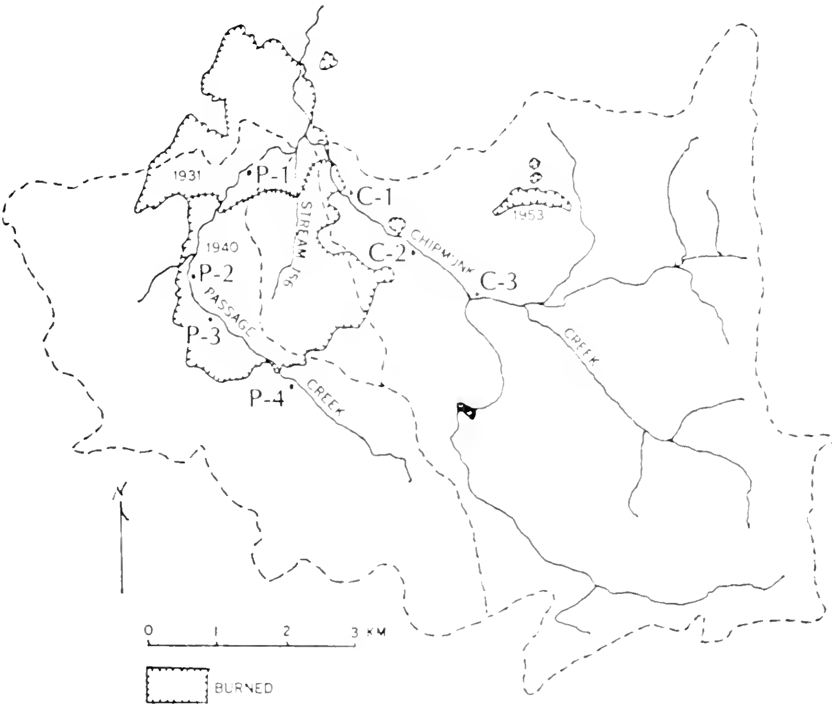

Figure 2. Chipmunk Creek-Passage Creek area, Yellowstone National Park, Wyoming. The 1931, 1940, and 1953 burns are shown. The dashed lines denote watershed boundaries. Locations of sampling stations C-1 through C-3 and P-1 through P-4 are shown.

There is still a distinct contrast between the 1931–1940 burned area and the surrounding forest (Figure 3). The landscape in the burned area is relatively open. Snags, standing and fallen, are present throughout the burn (Figure 4). Below standing snags, patches of lodgepole pine (about 4 m high in the 1940 burn and 6 m high in the 1931 burn) are recolonizing the burn area. The riparian area along Passage Creek is open; there is no overstory. The surrounding forest, which is about 300 years old, is very dense relative to the burned area. Along Chipmunk Creek, the overstory forms a tangle of foliage that shades most of the water surface (Figure 5). There is little low brush overhanging either Chipmunk Creek or Passage Creek.

1976 Continental Divide Fire Study Area

On 11 July 1976, lightning started a fire near the west shore of the South Arm

of Yellowstone Lake (Figure 1). A decision was made to allow the fire to burn. By 16 July, the Continental Divide fire had burned over most of its eventual area of 200 ha. The fire continued to smolder in spots until fall when it was extinguished, presumably by rain and snow. The overstory, which was completely killed, was mostly Engelmann spruce and subalpine fir; some lodgepole was also killed. The spruce and fir in the area were about 300 years old; the lodgepole pine dates back to about 1879 (D. G. Despain, Plant Biologist, U.S. National Park Service, pers. commun.).

Two small streams draining the Continental Divide into the South Arm, Yellowstone Park Streams Nos. 173 and 174, run through the burn (Figures 1 and 6). The watersheds of the two streams were almost entirely burned by the fire.

Figure 3. Chipmunk Creek, Yellowstone National Park, at the boundary of the burned area, about 1 km above the confluence with Passage Creek. *Photograph by the author, July 1976.*

MATERIALS AND METHODS

Chipmunk Creek-Passage Creek Study Area

The Chipmunk Creek-Passage Creek Study Area lies about 25 km from the nearest road. Access to the area was by boat from Lake, Wyoming to the end of the South Arm of Yellowstone Lake, and then by trail from there to the study area (Figure 1). All equipment and supplies were backpacked to the study area from the South Arm. Six trips were made to the study area at 2-week intervals between 21 June and 2 September 1976.

Stream temperature data on Chipmunk Creek and Passage Creek were gathered just above the confluence of the two streams. A pocket thermometer was used on 23 June. A dual probe recording thermograph (Belfort Instruments No.

5-1135) placed at the confluence recorded temperatures over 9-day periods in both streams starting 7 July, 21 July, 4 August, and 18 August, respectively. The thermograph was recalibrated before being put into operation each time it was used. Average daily temperatures were estimated from the thermograph charts by reading the charts at every 2-hour interval on the chart, and calculating the arithmetic average.

Figure 4. Passage Creek, Yellowstone National Park, in the area of the 1931 burn. *Photograph by the author, July 1976.*

Streamflow was measured in both streams near their confluence on each of the trips to the study area using the method of Robins and Crawford (1954). The areas of the watersheds of the two streams were determined with USGS topographic maps and a polar planimeter. From flow and drainage area data, daily water yields were estimated by dividing the daily discharge by the drainage area.

Water samples were taken from both creeks near the confluence on 23 June, 22 July, 5 August, and 31 August. The samples were analyzed for total dissolved solids (TDS), total hardness, calcium hardness, magnesium hardness, sodium, potassium, iron, manganese, copper, total alkalinity, phenolphthalein aklalinity, bicarbonate alkalinity, chloride, fluoride, sulfate, nitrate-nitrogen, Kjeldahl nitrogen, phosphate, orthophosphate, carbon dioxide, total organic carbon (TOC), silica, turbidity, and pH. Collection, preservation, and analysis of water samples were conducted according to *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association, et al. 1971). The water analyses were performed by Orlando Laboratories, Orlando, Florida. On 23 June and 22 July, pH was also determined in the field with a Hellige Color Comparator pH kit. From the water quality and water yield data, daily mineral export rates were estimated by multiplying concentration times daily water yield.

Figure 5. Chipmunk Creek, Yellowstone National Park, in unburned area. *Photograph by the author, July 1976.*

Figure 6. Yellowstone National Park Stream No. 174 after the 1976 Continental Divide fire. *Photograph by the author, July 1976.*

Aufwuchs accumulation on artificial substrates was used here as a comparative index of productivity between Chipmunk Creek and Passage Creek. The substrates were clear plexiglass plates, 15 cm^2 by 3 mm thick. A 16-mm diameter hole was drilled in each substrate; the hole was centered 14 mm in from the midpoint of one edge of the square substrate. Surface area of each side of the substrates was 223 cm^2. Each substrate was positioned in the stream by slipping it down a 13-mm diameter hardwood dowel driven into the stream bottom. One substrate, resting on the stream bottom, was used per dowel.

On 24 June, three artificial substrates were placed in the streams at each of Stations C-1, C-2, C-3, P-1, P-2, P-3, and P-4 (Figure 2). Station locations were matched with respect to elevation. Elevations of the stations were: C-1 and P-1, 2438 m; C-2 and P-2, 2487 m; C-3 and P-3, 2505 m; P-4, 2566 m. Station P-4, located in Passage Creek above the burned area, was chosen to provide a comparison of burned and unburned Passage Creek stations.

Accumulated aufwuchs were collected from the substrates on 7 and 8 July, 4 and 5 August, 18 and 19 August, and 1 and 2 September. Aufwuchs were collected from both sides of the substrates with a single-edge razor blade and a wash bottle with demineralized water. The collections were preserved in Lugol's solution (Slack, et al. 1973).

Due to decreasing stream water level, some substrates were partially or completely exposed after the first two accumulation periods. Samples from exposed substrates were used only for identification of aufwuchs organisms. Those substrates were later repositioned in deeper water for the following accumulation period. At the time of collection of each aufwuchs sample, percent sky, water depth, distance from nearest streambank, percent silt, percent sand, percent

gravel (0.5–5.0 cm), percent rubble (5–30 cm), and surface water velocity were estimated, in the immediate vicinity of the substrate. Water depth and distance from the nearest streambank were measured with a meter stick. Percent sky (the portion of the sky not blocked out by vegetation or hills), and percent silt, sand, gravel, and rubble were estimated by eye. Surface velocity was measured with a stopwatch and a float on a measured leader, or with a Gurley pygmy current meter, or, in the case of very slow velocities, with spit, meter stick, and stopwatch. Air and water temperatures were taken with a pocket thermometer at each station.

The ash-free weight of each sample was determined by weight loss on ignition at 500 C (American Public Health Association, et al. 1971). The ignition of blank samples confirmed that Lugol's solution added no ash-free weight to the samples.

Due to logistical problems, the nine Passage Creek aufwuchs samples collected 7 July were in the stream 13 days, the single Chipmunk Creek sample collected 4 August was in the stream 27 days, and the six Passage Creek samples collected 5 August were in the stream 29 days. All other aufwuchs samples were in the stream 14 days. For comparative purposes, the weights of the 16 samples with exposure times other than 14 days were converted to 14-day weights by linear interpolation or extrapolation. Analysis of covariance (Nie, et al. 1965) was used to determine if aufwuchs accumulation at the burned stations was significantly different from aufwuchs accumulation at the unburned stations.

To investigate the relationships between environmental variables and aufwuchs accumulation, a multivariate correlational analysis (Cooley and Lohnes 1971) was performed on the data. The variables were: (1) days past June 1 at time of collection (this variable should account for seasonal trends in aufwuchs accumulation), (2) elevation, (3) years since burn, (4) percent sky, (5) substrate depth, (6) substrate distance from nearest streambank, (7) percent silt, (8) percent sand, (9) percent gravel, (10) percent rubble, (11) surface velocity, and (12) 14-day ash-free weight of accumulated aufwuchs.

To compare the benthic macroinvertebrate communities of Chipmunk Creek and Passage Creek, benthic sampling in the two streams was conducted on 22 July. Samples were taken at Station C-1 in Chipmunk Creek and at Station P-1 in Passage Creek (Figure 2). The Chipmunk Creek sampling site was in a well-shaded riffle, typical of that stream. The Passage Creek sampling site was in an unshaded riffle, typical of that stream.

Due to the variety of physical habitats found even within a single physically uniform riffle, the distribution of benthic organisms in it tends to be very irregular. In reappraising the data of Needham and Usinger (1956), Chutter (1972) calculated that 448 Surber samples (Surber 1936) would have been necessary to be 95% confident of being within 5% of the true mean of the number of benthic macroinvertebrates per ft ^{2} in a single riffle in Prosser Creek, California.

Due to the difficulty of obtaining good estimates of benthic macroinvertebrate populations over an entire riffle, benthic sampling was limited to a narrowly defined physical biotope. Reliable estimates of composition and size of populations within a narrow biotope may be obtained with relatively few samples. Differences in that biotope's benthic populations between streams could be indicative of general benthic population differences between streams. Benthic sampling was therefore arbitrarily limited to the biotope defined by the following

physical parameters: distance from streambank, 0.5–1.5 m; depth, 0.15–0.25 m; surface velocity, 0.5–0.7 m/sec; substrate mainly of 5–15 cm rubble. Velocity was measured with a stopwatch and a float attached to a measured leader. A portable invertebrate box sampler (PIBS) (Ellis-Rutter Associates, Douglassville, PA) with a net of 0.35 mm mesh was used to collect eight benthic samples within the biotope at each sampling riffle. Sampling time was 8 minutes per sample.

The organisms in the benthic samples were preserved in 70% EtOH, identified, and counted. For each sample, a diversity index was calculated using the formula:

$$\bar{d} = -\sum_{i=1}^{s} \left(\frac{n_i}{n}\right) \log_2 \left(\frac{n_i}{n}\right)$$

where n is the total number of individuals in the sample, n_i is the number of individuals in the i^{th} taxon, s is the total number of taxa, and $\bar{d}$ is diversity (Slack, et al. 1973). The diversity index is a reflection of the number of different taxa in the sample.

To capture downstream migrant cutthroat trout fry, drift nets were set at Station C-1 in Chipmunk Creek and at 0.5 km above the confluence in Passage Creek on 21 and 22 July and again on 18 and 19 August. The nets were 30.5 cm square by 1 m deep. The net material was Nitex® No. 656.

1976 Continental Divide Fire Study Area

Access to the Continental Divide Fire area was by boat from the South Arm of Yellowstone Lake. Streams 173 and 174 (Figure 1) were studied on 19 July, 23 July, 27 July, 3 August, and 9 September. On each trip, stream temperatures were taken with a pocket thermometer, and general observations of the aquatic biota were made. On 19 July, 3 August, and 9 September, water samples for chemical analysis were taken at the mouths of the streams. The chemical tests performed and the methods used were the same as those for Chipmunk Creek and Passage Creek water samples. The July 19 samples were taken when the fire was burning actively. The August 3 samples were taken during a rainstorm which was contributing some surface runoff to the streams. The September 9 samples were taken on a clear day with no surface runoff. The fire was still smoldering in spots on 3 August and 9 September.

RESULTS

Chipmunk Creek-Passage Creek Study Area

On 23 June, the temperature of Chipmunk Creek was 1.1 C warmer than the temperature of Passage Creek. In all subsequent measurements, the daily average temperature of Passage Creek was between 1.3 and 2.2 C warmer than that of Chipmunk Creek (Figure 7). The difference between the weekly average temperatures of the two streams was widest in late July (1.9 C), when the weekly average temperatures were warmest (12.4 C in Chipmunk Creek, 14.3 C in Passage Creek). The diurnal temperature fluctuation patterns of Chipmunk Creek and Passage Creek were nearly identical and parallel; temperatures were lowest at about 0600 hours and highest at about 1500 hours. Diurnal temperature fluctuations in both creeks ranged from 2.2 to 11.7 C. The highest instantaneous

temperatures recorded were 19.4 C in Chipmunk Creek on 24 July and 20.9 C in Passage Creek on 25 July. The lowest instantaneous temperatures recorded were 3.9 C in Chipmunk Creek on 27 August and 5.8 C in Passage Creek on 27 August. The air and water temperatures at each aufwuchs collection station were always taken sometime between 0920 and 1620 hours. Air temperature was in all cases warmer than water temperature.

Streamflow in Chipmunk Creek and in Passage Creek decreased to less than one-tenth of the initial values during the study period (Table 1). Chipmunk Creek flow dropped from 4.06 m^3/sec on 23 June to 0.29 m^3/sec on 31 August; Passage Creek flow dropped from 4.24 m^3/sec on 23 June to 0.11 m^3/sec on 31 August. Thus Passage Creek flow was initially slightly greater than Chipmunk Creek flow; in late August, Passage Creek flow was less than half than the flow of Chipmunk Creek.

TABLE 1. Flow and Water Yield for Chipmunk Creek and Passage Creek, Yellowstone National Park, Summer 1976.

	Flow (m^3/sec)		*Water Yield ($m^3/ha/day$)*	
	Chip.	*Pass.*	*Chip.*	*Pass.*
23 Jun	4.06	4.24	89.3	173
8 Jul	1.55	1.29	34.1	52.6
21 Jul	0.66	0.50	14.5	20
4 Aug	0.45	0.20 (5 Aug)	9.9	8.2 (5 Aug)
18 Aug	0.32	0.16	7.0	6.5
31 Aug	0.29	0.11	6.4	4.3

Daily water yield per ha of watershed also decreased from June to September in both creeks (Table 1). Chipmunk Creek water yield dropped from 89 $m^3/ha/day$ on 23 June to 6.4 $m^3/ha/day$ on 31 August; Passage Creek water yield dropped from 173 $m^3/ha/day$ on 23 June to 4.3 $m^3/ha/day$ on 31 August. In June and early July, water yield was much higher in Passage Creek than in Chipmunk Creek. In August, water yield was slightly higher in Chipmunk Creek than in Passage Creek. Total water yields for the 6 days measured were 161.2 m^3/ha in Chipmunk Creek and 264.9 m^3/ha in Passage Creek.

In general, chemical concentrations in Chipmunk Creek were not markedly different from chemical concentrations in Passage Creek (Table 2). TDS values were slightly higher in Chipmunk Creek than in Passage Creek. TDS in Chipmunk Creek rose from 27 mg/l on 23 June to 82 mg/l on 31 August; TDS in Passage Creek rose from 24 mg/l on 23 June to 75 mg/l on 31 August. There were no consistent differences in calcium, magnesium, or sodium ion concentrations between the two creeks. Potassium concentration was consistently higher in Chipmunk Creek (average, 1.28 mg/l) than in Passage Creek (average, 1.06 mg/l). There were no differences found in iron, manganese, and copper concentrations between the two creeks. There were no consistent differences found in alkalinity, chloride, fluoride, sulfate, or nitrate-nitrogen concentrations. Except in the August 31 samples, more Kjeldahl nitrogen was found in Chipmunk Creek than in Passage Creek. On 22 July and 31 August, phosphate was slightly higher in the Chipmunk Creek samples than in the Passage Creek samples. Carbon dioxide, TOC, silica, turbidity, and pH showed no consistent differences between the two creeks. The August 31 Passage Creek sample had the highest pH and the lowest carbon dioxide concentration of any sample.

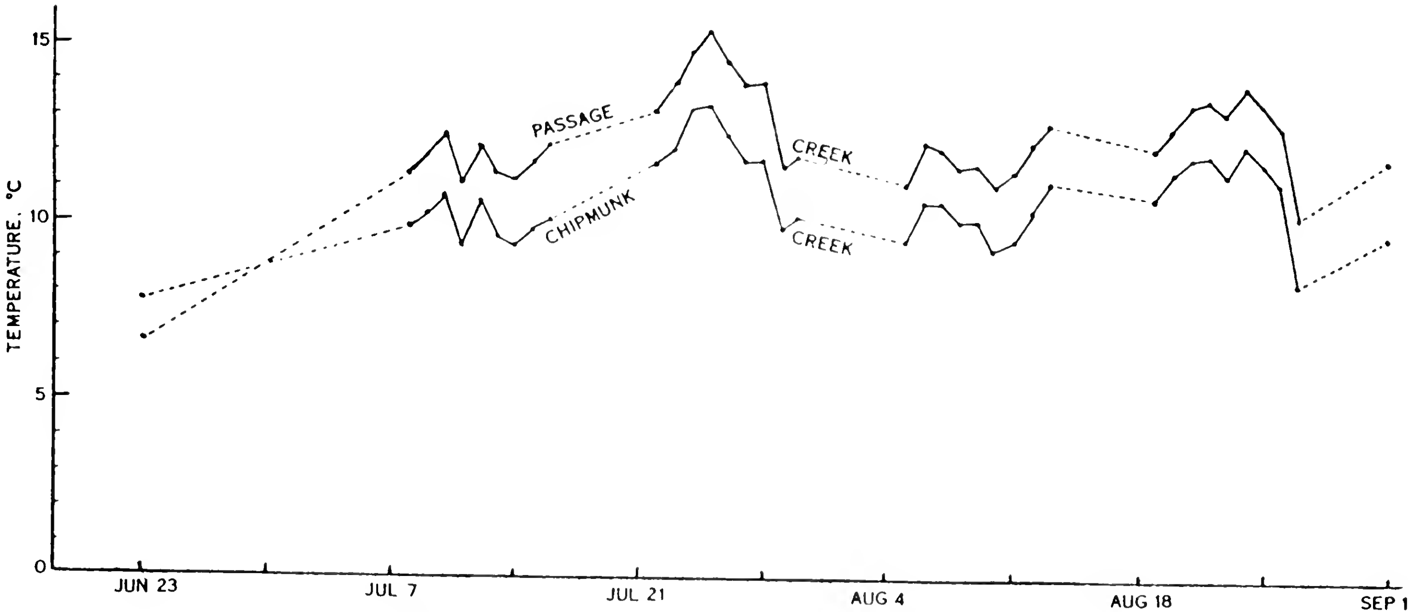

Figure 7. Average daily stream temperatures in Chipmunk Creek and Passage Creek, Yellowstone National Park, Wyoming, at the confluence of the two creeks, summer 1976. The 23 June values are single measurements taken at 1300 hours.

TABLE 2. Water Quality in Chipmunk Creek and Passage Creek, Yellowstone National Park, Wyoming, Summer 1976.

	23 June		*22 July*		*5 Aug.*		*31 Aug.*	
Substance (mg/1)	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*
TDS	27	24	62	57	55		82	75
*Total hardness	16	16	26	24	24		28	24
*Calcium hardness	12	12	20	20	20		22	18
*Magnesium hardness	4	4	6	4	4		6	6
Sodium	1.9	1.5	2.1	1.7	2.5		8	9
Potassium	1.0	0.68	1.24	1.08	1.20		1.69	1.42
Iron	0.2	0.2	0.05	0.05	0.05		0.1	<0.1
Manganese	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	<0.05
Copper	<0.1	<0.1	<0.1	<0.1	<0.1		<0.1	<0.1
*Total alkalinity	14	14	28	26	24		40	40
*Carbonate alkalinity	0	0	0	0	0		0	4
*Bicarbonate alkalinity	14	14	28	26	24		40	36
Chloride	1	1	<1	<1	1		3	3
Fluoride	<0.1	<0.1	0.10	0.10	0.1		0.06	0.13
Sulfate	3	1	4	3	3		3	3
Nitrate-nitrogen	0.06	0.05	0.03	0.02	0.02		0.02	0.02
Kjeldahl nitrogen	0.53	<0.01	0.36	<0.01	0.08		<0.01	<0.01
Phosphate, as PO_4	<0.1	0.1	0.17	0.13	0.16		0.20	0.16
Orthophosphate, as PO_4	<0.1	0.1	0.17	0.13	0.16		0.20	0.16
Carbon dioxide	1.9	2.2	1.6	2.2	1.3		2.1	<1.0
Total organic carbon	9.9	7.5	5.2	8.6	3.2		0.60	1.05
Silica, as SiO_2	5	5	11	10	10		10	8.8
Turbidity, NTU	1.0	0.9	0.56	0.38	0.43		0.27	0.41
pH (Laboratory)	7.2	7.1	7.6	7.4	7.6		7.6	8.4
pH (Field	7.2	7.2	7.6	7.5				

Lost Sample
*as $CaCO_3$

Mineral export was generally higher in the Passage Creek watershed than in the Chipmunk Creek watershed on 23 June and 22 July, and higher in the Chipmunk Creek watershed on 31 August (Table 3). Due to higher overall water yield in Passage Creek, the 3-day totals of estimated export were generally higher in Passage Creek than in Chipmunk Creek. In the 3 days measured, TDS export estimates were 5633 g/ha in Passage Creek and 3726 g/ha in Chipmunk Creek. Sulfate ion was the only substance with higher 3-day export in Chipmunk Creek (341 g/ha) than in Passage Creek (247 g/ha).

A total of 67 aufwuchs samples (36 from unburned stations and 31 from burned stations) was gravimetrically analyzed. Mean aufwuchs accumulation was 32.6 mg per substrate at the burned stations and 22.9 mg per substrate at the unburned stations (Table 4). Analysis of covariance, however, showed the difference to be statistically insignificant ($p = 0.146$).

The main diatoms found on the artificial substrates from both streams were of the genera *Synedra, Ceratoneis, Denticula, Gomphonema,* and *Cocconeis.* The green alga *Ulothrix* was also found. Tendipedid larvae and Ephemeroptera naiads were found grazing on some substrates, in which case they were included in the sample.

Aufwuchs accumulation was positively correlated most strongly with percent silt ($r = 0.50$) and days past 1 June (indicates a seasonal trend) ($r = 0.43$), and

was negatively correlated most strongly with surface water velocity (r = −0.42). Other correlations showed that higher surface velocity was associated with larger substrate sizes, and that the older the burn, the less sky was visible through the canopy. Multiply regression analysis showed that 49% of the variation in aufwuchs accumulation could be predicted by all the other variables measured, and that 33% of that variation could be predicted by the variables percent silt, days past 1 June, and surface water velocity.

TABLE 3. Mineral Export, g/ha/day, in Chipmunk Creek and Passage Creek Watersheds, Yellowstone National Park, Wyoming, Summer 1976.

	Export, g/ha/day							
	23 June		*22 July*		*31 Aug.*		*Totals*	
Substance	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*	*Chip.*	*Pass.*
TDS	2410	4147	900	1162	416	324	3726	5633
*Total hardness	1428	2765	377	489	142	103	1947	3357
*Calcium hardness	1071	3629	290	408	112	78	1473	4115
*Magnesium hardness	357	691	87	82	30	26	474	799
Sodium	170	259	30	35	41	39	241	333
Potassium	89	118	18	22	8.6	6.1	116	146
Iron	18	35	0.7	1				
*Total alkalinity	1250	2419	406	530	203	173	1859	3122
Chloride	89	173			15	13		
Fluoride			1.4	2	0.3	0.56		
Sulfate	268	173	58	61	15	13	341	247
Nitrate-nitrogen	5.4	8.6	0.4	0.4	0.1	0.09	5.9	9.1
Phosphate, as PO_4		17.3	2.5	2.6	1.0	0.69		20.6
Silica, as SiO_2	446	864	160	204	51	38	657	1106

*as $CaCO_3$

TABLE 4. Ash-free Weights, in mg, of Aufwuchs Accumulated 14 Days on Artificial Substrates at Burned and Unburned Stations in Chipmunk Creek and Passage Creek, Yellowstone National Park, Summer 1976. Values in Parentheses are Corrected 14-day Weights for Samples Collected After Periods Other than 14 Days. Asterisks Indicate Missing or Exposed Substrates.

	Burned			*Unburned*			
	P-1	*P-2*	*P-3*	*P-4*	*C-1*	*C-2*	*C-3*
7–8 July	5.0 (5.4)	2.5 (2.7)	3.1 (3.3)	1.5 (1.6)	3.0	2.2	5.1
	5.4 (5.8)	0.6 (0.6)	*	2.7 (2.9)	13.3	4.3	10.0
	51.1 (55.0)	2.3 (2.5)	*	*	5.7	0.3	1.5
4–5 Aug.	*	32.3 (15.7)	36.5 (17.6)	*	39.4 (20.4)	*	*
	*	43.3 (20.9)	19.0 (9.2)	*	*	*	*
	*	47.6 (23.0)	23.4 (11.3)	*	*	*	*
18–19 Aug.	170.6	18.7	61.8	40.7 (38.0)	16.5	41.0	8.1
	54.1	14.9	50.5	33.9 (31.6)	80.8	20.1	13.7
	55.5	22.3	40.8	19.0 (17.7)	90.9	9.9	13.4
1–2 Sept.	38.0	14.7	18.0	20.9	26.3	72.8	14.9
	69.5	20.1	23.7	32.5	23.2	27.5	19.2
	106.7	21.8	35.0	54.3	32.8	11.6	34.7
	n = 31			n = 36			
	$\bar{x}$ = 32.6			$\bar{x}$ = 22.9			

More benthic macroinvertebrate individuals were found in the Passage Creek benthic samples than in the Chipmunk Creek benthic samples (Tables 5 and 6).

The Mann-Whitney U-Test (Sokal and Rohlf 1969) was applied to the data and the difference was found to be statistically significant ($p<0.05$). The difference was most evident in the Acari (1088 in Passage Creek, 138 in Chipmunk Creek), the Coleoptera (104 in Passage Creek, 17 in Chipmunk Creek), the Ephemeroptera (1144 in Passage Creek, 366 in Chipmunk Creek), and the Plecoptera (446 in Passage Creek, 204 in Chipmunk Creek). Fewer Trichoptera were found in Passage Creek (89 individuals) than in Chipmunk Creek (191 individuals).

The diversity indices of the Passage Creek benthic samples (Table 6) were generally higher than the diversity indices of the Chipmunk Creek benthic samples (Table 5). The Mann-Whitney U-Test was applied, and the difference was found to be statistically significant ($p<0.05$).

TABLE 5. Benthic Macroinvertebrate Samples Taken from Chipmunk Creek, at Altitude 2438 m, Yellowstone National Park, Wyoming.

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total*	
Acari										*138*
sp. 1	15	9	5	8	24	8	17	23	109	
sp. 2	1	2		4	2	1	1	3	14	
sp. 3	2		1		2	1	6	3	15	
Coleoptera										*17*
Gonielmis					7		1		8	
Hydrovatus			5	1		3			9	
Collembola										*2*
Sminthurus								2	2	
Diptera										*1563*
Chironomidae sp. 1	128	43	123	142	267	239	116	287	1345	
Chironomidae sp. 2	19	34	10	26	38	19	20	18	184	
Atherix		1							1	
Simuliidae sp. 1			3			1			4	
Diptera sp. 1	11		1	1	10	4	2		29	
Ephemeroptera										*366*
Baetis	29	19	20	11	18	24	13	13	147	
Cinygmula	21	2	19	23	31	17	13	12	138	
Epeorus	7	3	2	3			3		18	
Ephemerella			7	2	2	1			12	
Heptagenia	4	5	7	3	3	1	3	1	27	
Pseudo cloeon		2		5			7	6	20	
Rhithrogena							2	2	4	
Plecoptera										*204*
Acroneuria		1						1	2	
Alloperla	16	4	13	9	31	16	8	6	103	
Isogenus	4	8	4	4	11	10	8	9	58	
Nemoura	4	7	6	1		1	6	6	31	
Paragentina			7		3				10	
Trichoptera										*191*
Arctopsyche	2	2	8	1			3	2	18	
Dicosmoecus					1	2			3	
Micrasema			1						1	
Neothremma	10	14	19	18	3	5	17	8	94	
Polycentropus	9	3	10	3	7	5	6	1	44	
Rhyacophila		2	4		1		1	4	12	
Sericostoma	4	1	4			6	2	2	19	
Totals	286	162	279	265	461	364	255	409	2481	
Diversity index	2.96	3.32	3.22	2.57	2.40	2.13	3.09	1.98		

TABLE 6. Benthic Macroinvertebrate Samples Taken from Passage Creek, at Altitude 2438 m, Yellowstone National Park, Wyoming.

Sample	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total*	
Acari										*1088*
sp. 1	42	97	360	62	110	62	147	100	980	
sp. 2	1	5	9	3	9	9	8	7	51	
sp. 3	5	9	18	3	5	5	9	3	57	
Coleoptera										*104*
Carabidae sp. 1	1			1		1			3	
Cleptelmis	13	13	24	1	11	7	22	10	101	
Collembola										*1*
Sminthurus		1							1	
Diptera										*1250*
Anthomyiidae sp. 1		1							1	
Chironomidae sp. 1	118	54	94	39	105	164	104	74	752	
Chironomidae sp. 2	46	75	105	22	98	23	43	66	478	
Hexatoma	3		2						5	
Limnophila					2				2	
Simuliidae sp. 1	2	1	2	1	1	2		1	10	
Diptera sp. 1			1	1					2	
Ephemeroptera										*1144*
Baetis	58	22	33	22	27	14	60	12	248	
Callibaetis		3	1	1			3	2	10	
Centroptilum	38	28	31	37	103	43	29	14	323	
Cinygmula	43	31	54	21	35	69	69	41	363	
Epeorus	4	8	3	1	2	5	4	4	31	
Ephemerella	4	5				1	1		11	
Heptagenia		1				1	1		3	
Paraleptophlebia	14	10	36	10	25	30	6	17	148	
Pseudocloeon		1							1	
Rithrogena	6								6	
Hemiptera										*5*
Aphididae sp. 1			1						1	
Corixidae sp. 1						1			1	
Mesovelliidae sp. 1	1						1	1	3	
Megaloptera										*2*
Sialidae sp. 1	2								2	
Plecoptera										*446*
Acroneuria	6	1	4		2	4	9	2	28	
Alloperla	25	19	97	15	33	55	57	34	335	
Isogenus	12	8	9	4	7	10	18	11	79	
Nemoura			1			1	2		4	
Trichoptera										*89*
Arctopsyche	2								2	
Brachycentrus	2	1							3	
Dicosmoecus	1		2				1		4	
Neothremma	1	8	5	2	6	6	4	1	33	
Rhyacophila	4	5	12	4	4	5	10	3	47	
Totals	454	407	904	250	583	520	608	403	4129	
Diversity index	3.53	3.49	3.02	3.26	3.18	3.26	3.39	3.19		

There were spawning runs of cutthroat trout in Chipmunk Creek and in Passage Creek. Adult fish exhibiting spawning behavior were seen in many areas of both creeks on June 22–23.

No cutthroat trout fry were captured or seen in the 21 and 22 July drift net sampling. In the 18 and 19 August sampling, 273 fry were captured from Chipmunk Creek and 47 fry were captured from Passage Creek. Fry lengths from

Chipmunk Creek ranged from 22–38 mm (mean, 26.4 mm); fry lengths from Passage Creek ranged from 23–36 mm (mean, 26.6 mm). Thus there was no difference found in fry lengths between the two creeks.

On 4 and 5 August, cutthroat trout fry were observed at three different locations in the burned area of Passage Creek, and in the lower reaches of Yellowstone Park Stream No. 156, which lies entirely within the burned area (Figure 2), but nowhere in Chipmunk Creek. Cutthroat trout fry were observed in abundance in both Chipmunk Creek and Passage Creek on the next trip to the study area, 18 August. Fry apparently emerged from the gravel earlier in Passage Creek than in Chipmunk Creek.

1976 Continental Divide Fire Study Area

Fire burned to the water's edge of Streams 173 and 174 (Figure 6). The watersheds were covered by a layer of ash and charred debris. Charred trees fell across the streams, and bits of charred debris were present on the stream bottoms. No visible turbidity was ever observed in the streams. There was no evidence of ash being washed directly into the streams.

The highest temperature found in either stream during or after the fire was 12 C. Calcium, magnesium, potassium, chloride, sulfate, phosphate, TOC, and turbidity were higher in both streams during the rainstorm of 3 August than on the dry days of 19 July and 9 September (Table 7). Calcium and magnesium concentration were both 2 mg/l (as $CaCO_3$) higher in the 3 August samples than in the 19 July and 9 September samples. Potassium concentrations were about 0.5 mg/l higher in the 3 August samples than in the other samples. Chloride ion was raised to detectable concentrations in the 3 August samples. Phosphate concentrations on 3 August were about four times the concentrations on 19 July and 9 September. The increase in turbidity in the 3 August samples was not great enough to be detectable by eye. Sodium concentrations were lower in the 3 August samples than in the 19 July and 9 September 9 samples.

Benthic insects were observed in both streams during and after the fire; they were abundant and no dead insects were seen. Cutthroat trout eggs in a redd in Stream 174 appeared normal and in good condition on 23 July, during the fire. Fry emerged from the gravel in both streams, and they appeared normal and healthy on 9 September.

DISCUSSION

Chipmunk Creek-Passage Creek Study Area

Passage Creek was cooler than Chipmunk Creek on 23 June (Figure 7). The lower water temperature found in Passage Creek on that day may have been due to greater exposure to lower air temperatures. Snow fell in the study area on the afternoon of 23 June, so mid-afternoon air temperatures were probably cooler than water temperatures (6.7 C in Passage Creek, 7.8 C in Chipmunk Creek), possibly resulting in a greater cooling effect on more exposed Passage Creek than less exposed Chipmunk Creek.

In all measurements taken after 23 June, Passage Creek was warmer than Chipmunk Creek (Figure 7). Passage Creek is less shaded than Chipmunk Creek (Figures 4 and 5), so the persisting pattern of warmer temperatures in Passage Creek than in Chipmunk Creek during the summer was probably due at least

partially to more solar radiation reaching Passage Creek than Chipmunk Creek. After 23 June, all measurements of daytime air and water temperatures at the aufwuchs collection stations showed daytime air temperatures to be warmer than daytime water temperatures. Therefore, the persisting pattern of warmer temperatures in Passage Creek than in Chipmunk Creek during the summer may also have been due to greater exposure to warmer air temperatures in Passage Creek than in Chipmunk Creek.

TABLE 7. Water Analysis of Yellowstone Park Streams 173 and 174, Summer 1976, During and After a Fire Burned Their Drainages. The 3 August Samples were Taken During a Rainstorm. There was No Rain When the 19 July and 9 September Samples were Taken.

Date	July 19		Aug. 3		Sept. 9	
Substance (mg/1) Stream	173	174	173	174	173	174
TDS	78	66	78	68	90	65
*Total hardness	36	28	40	32	36	28
*Calcium hardness	24	18	26	20	24	18
*Magnesium hardness	12	10	14	12	12	10
Sodium	3.7	3.5	2.8	2.6	3.2	2.8
Potassium	2.00	1.52	2.52	1.78	1.94	1.37
Iron	0.06	0.08	0.1	0.1	0.1	0.1
Manganese	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
*Total alkalinity	40	32	34	32	44	34
*Phenolpthalein alk.	0	0	0	0	0	0
*Bicarbonate alk.	40	32	34	32	44	34
Chloride	<1	<1	2	1	<1.0	1.0
Fluoride	0.15	0.31	0.2	0.3	0.2	0.3
Sulfate	3	3	6	4	2	2
Nitrate-nitrogen	0.02	0.04	0.03	0.04	0.04	<0.01
Kjeldahl nitrogen	0.07	0.13	0.02	0.36	0.02	0.02
Phosphate, as PO_4	<0.1	<0.1	0.52	0.60	0.23	0.10
Orthophosphate, as PO_4	<0.1	<0.1	0.50	0.55	0.23	0.10
Carbon dioxide	5.2	4.1	4.5	5.4	2.3	1.9
Total organic carbon	4.8	6.4	9.5	7.1	0.72	0.55
Silica, as SiO_2	10	11	13	10	16	12
Turbidity, NTU	0.3	0.6	0.50	1.8	0.24	0.48
pH (Laboratory)	7.2	7.2	7.2	7.1	7.6	7.6
pH (Field)	7.2	7.2	7.2	7.2	7.4	7.3

* as $CaCO_3$

Shading acts as a temperature buffer on streams. Edington (1966) found that, in northern England, shaded reaches of streams were cooler in summer, and warmer in winter, than unshaded reaches. Chipmunk Creek and Passage Creek both probably freeze in winter, but due to greater exposure, Passage Creek may warm faster to warmer air temperatures in spring, and cool faster to cooler air temperatures in fall, than Chipmunk Creek.

The greatest difference in average daily temperatures found between Chipmunk Creek and Passage Creek was 2.2 C. Burned areas at lower elevations, at lower altitudes, or with more southerly exposures than the Chipmunk Creek-Passage Creek area may have greater increases in summertime stream temperatures than were found in the Chipmunk Creek-Passage Creek area. Helvey (1972) found that late summer stream temperatures increased up to 5.6 C in a south-facing burned watershed in Washington.

During the summer, Passage Creek flow decreased more than Chipmunk Creek flow (Table 1). Flow per ha of watershed of Passage Creek was greater than that of Chipmunk Creek in early summer, and was less than that of Chipmunk Creek in late summer. Higher early summer flows in Passage Creek could be caused by faster snowmelt in the less shaded burned area, by decreased moisture retention capacity of the burned soil resulting in faster runoff (Dyrness 1963), by decreased plant transpiration due to less vegetation in the burned area, or by a combination of the three factors. The first two factors could cause the lower late summer flows found in Passage Creek. A greater influence of springs in Chipmunk Creek than in Passage Creek could also cause the late summer difference.

Estimated total water yield for the 6 days measured was higher in Passage Creek than in Chipmunk Creek. The 6 days for which water yield was estimated were evenly distributed at 2-week intervals during the study period, so trends in water yield for the study period are probably accurately represented by the 6-day totals. The water yield results may be indicative of higher annual water yield in Passage Creek than in Chipmunk Creek. The difference in vegetation density and plant transpiration between the burned area of the Passage Creek watershed and the unburned Chipmunk Creek watershed may be still great enough to cause a difference in water yield between the two watersheds, 36 years after the more recent burn. Helvey (1972), Pase and Ingebo (1965), and Wright (1976) all reported increased annual water yields the first few years after fires. In the study of Pase and Ingebo (1965), annual water yield was again approaching control levels by the fourth year after fire.

Chemical concentrations in Chipmunk Creek were not consistently different from chemical concentrations in Passage Creek (Table 2); there was no evidence of enrichment by increased concentrations of chemical nutrients in Passage Creek. Potassium concentration was consistently slightly higher in Chipmunk Creek than in Passage Creek. In the 31 August samples, pH was higher and carbon dioxide concentration was lower in Passage Creek than in Chipmunk Creek. Those samples were taken in late afternoon on a cloudless day, so those chemical conditions may have been a result of a higher rate of instream photosynthesis in Passage Creek than in Chipmunk Creek.

Mineral export per ha of watershed was higher in Passage Creek than in Chipmunk Creek in late June and July, and was higher in Chipmunk Creek than in Passage Creek in late August (Table 3). Chemical concentrations in the two streams were similar (Table 2), so water yield per ha of watershed was the main factor controlling mineral export per ha of watershed. On the 3 days measured, the stream with the higher water yield had the higher mineral export (Tables 1 and 3). In view of the higher summer water yield found in Passage Creek than in Chipmunk Creek, summer mineral export was probably also higher in Passage Creek than in Chipmunk Creek. Higher mineral export in Passage Creek might increase the productivity of attached aquatic flora in that creek, due to increased flux of available nutrients past the attached flora.

Tiedemann and Helvey (1973) found that increased annual water yield was the factor responsible for increased annual cation export after a fire in eastern Washington. In the year after a fire in northeastern Minnesota, Wright (1976) found increased export of potassium and phosphorus, due to increased water yield and to increased concentrations.

Mean aufwuchs accumulation was nearly 50% higher at the burned stations than at the unburned stations (Table 4), but the difference was not statistically significant. The three highest correlations with aufwuchs accumulation were days past 1 June, percent silt, and surface velocity. The main trend that the correlational analysis revealed was that as summer progressed, surface velocities became slower, and aufwuchs accumulation became greater. Water velocity is an important factor in the attachment of algae in streams; the faster the current, the greater is the tendency for the more loosely attached species to be washed downstream (Whitton 1975). Despite greater water yield, there was no evidence of excessive scouring in Passage Creek. In addition to slower current velocities, increasing nutrient concentrations as summer progressed (Table 2) may also have stimulated growth of aufwuchs in the later samples.

The significantly greater number of benthic macroinvertebrates found in the Passage Creek samples than in the Chipmunk Creek samples could be indicative of a general difference in benthic macroinvertebrate populations between the two study streams. Such a general difference could be due to more instream primary production and/or to more allochthonous litter fall in Passage Creek than in Chipmunk Creek. There was no visually obvious difference in allochthonous litter fall between the two streams. Increased instream primary production, due to more sunlight and greater mineral export, could cause greater benthic macroinvertebrate populations in Passage Creek. The algal grazers *Baetis, Cinygmula,* and *Epeorus* (mayflies) were found in much greater numbers in Passage Creek samples (Table 6) than in the Chipmunk Creek samples (Table 5). Higher populations of algal grazers could, in turn, account for the higher numbers of the predators *Acroneuria, Alloperla,* and *Isogenus* (stoneflies) found in the Passage Creek samples than in the Chipmunk Creek samples. Generally higher benthic macroinvertebrate production in Passage Creek could result in higher resident trout production in that creek, due to more available energy to the fish from the preceding (macroinvertebrate) trophic level.

The higher diversity indices of the Passage Creek samples are a reflection of the greater number of taxa found in Passage Creek (36 taxa) than in Chipmunk Creek (30 taxa). If, as the benthic samples indicate, there are more benthic macroinvertebrate taxa in Passage Creek than in Chipmunk Creek, then Passage Creek may have a greater variety of benthic macroinvertebrate food species available to trout.

Based on the field observations, the actual difference in time of trout fry emergence between Chipmunk Creek and Passage Creek could theoretically have been as short as 1 day or as long as 27 days, because the sampling interval was 2 weeks. A more precise estimate of the difference can be made using the stream temperature data. In the 4 weeks preceding August 5, the date when fry were first seen in Passage Creek, the recording thermograph was in operation July 8–16 and July 22–30. Average stream temperatures during those 18 days, when eggs should have been in the gravel, were 10.9 C in Chipmunk Creek and 12.7 C in Passage Creek. Yellowstone cutthroat trout eggs hatch in 24 days at 14.2 C (U.S. Fish and Wildlife Service, unpublished data), for an average of 612 temperature units to hatch. Based on 612 temperature units and average stream temperatures of 10.9 C in Chipmunk Creek and 12.7 C in Passage Creek, Yellowstone cutthroat trout eggs would have hatched in 31 days in Chipmunk Creek and in 27 days in Passage Creek. Thus, on the average, fry in Passage Creek could

have emerged and drifted down to Yellowstone Lake about 4 days earlier than fry from Chipmunk Creek.

The changes in stream shading, temperature, flow, and benthic macroinvertebrates found in Passage Creek appear to be long-term effects of fire; they are still manifest decades after the burns. Those long-term effects could have many effects on Yellowstone cutthroat trout that use Passage Creek only as spawning habitat, and also on those trout that are resident throughout the summer.

Potential effects on spawning fish from Yellowstone Lake would be due to temperature and flow differences. Water temperature is an important cue in the migration of fish that live in lakes and breed in streams (Hynes 1970). In Yellowstone Lake tributaries, spawning runs of Yellowstone cutthroat trout commence in early summer when stream temperatures rise to about 8.5 C (J. D. Varley, Fishery Management Biologist, U.S. Fish and Wildlife Service, pers. commun.) If Passage Creek warms faster than Chipmunk Creek, then the Passage Creek run could commence earlier than the Chipmunk Creek run. The cumulative effect of earlier spawning and shorter egg incubation in Passage Creek could result in a difference in time of fry emergence greater than 4 days. By drifting down to Yellowstone Lake sooner, fry from Passage Creek could attain a competitive advantage over fry from Chipmunk Creek, based on zooplankton work in Yellowstone Lake (Varley, pers. commun.) The higher early and midsummer water yield in Passage Creek may result in easier fish access to the upper reaches of the creek, and in more available spawning habitat, than before the fires.

Populations of Yellowstone cutthroat trout that are summer residents of Passage Creek could be affected by other long-term effects of fire, in addition to effects on spawning and egg incubation time. In the subalpine climate of the Yellowstone Lake area, low water temperatures are a limiting factor to trout production. The warmer summertime temperatures of Passage Creek may increase trout growth and production in that creek, as compared to Chipmunk Creek. If benthic macroinvertebrate populations are higher in Passage Creek than in Chipmunk Creek as these results suggest, then there may be a beneficial effect on resident trout production.

1976 Continental Divide Fire Study Area

The observed temperatures in Streams 173 and 174 did not approach levels that would be limiting to trout, either during or after the fire.

No drastic increases of dissolved materials occurred in Streams 173 and 174; with exception of phosphorus, general levels of dissolved materials were comparable to those in Chipmunk Creek and Passage Creek at about the same time (Tables 2 and 7).

McColl and Grigal (1975) and Wright (1976) found that, after fire, phosphorus concentrations were higher in surface runoff waters, but were unchanged in stream and lake waters. They theorized that phosphorus is leached from ash by surface runoff, but that the phosphorus is again immobilized as the runoff percolates through deeper, unburned soil layers. Grier (1975) found a similar phenomenon for calcium, magnesium, and potassium leached from ash into soil after fire. The water quality data of Streams 173 and 174 (Table 7) indicate that this phenomenon may have occurred in the Continental Divide Fire area. Calcium, magnesium, potassium, chloride, sulfate, phosphate, and TOC concentra-

tions were raised somewhat when the rainstorm of August 3 was probably causing some surface runoff to reach the streams directly. On July 19 and September 9, there was no rain, and all water probably reached the streams as subsurface flow.

Higher phosphorus concentrations from stream outflow during the storm may have stimulated primary productivity in the South Arm in the vicinity of the mouths of Streams 173 and 174. Over a number of years, natural fire management may result in greater productivity in Yellowstone Lake due to a greater influx of nutrients from a number of burns. Further research in this area is needed.

Despite the drastic changes that fire made on the terrestrial community in the watersheds of Streams 173 and 174, life in the streams proceeded apparently undisturbed. No evidence was found that the fire had any immediate effect on aquatic life in those streams.

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REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard Methods for the Examination of Water and Waste Water. American Public Health Association, New York. 874 pp.

Chutter, F. U. 1972. A reappraisal of Needham and Usinger's data on the reliability of a stream fauna when sampled with a Surber sampler. Limnol Oceanogr. 17. 139–141

Cooley, W. W. and P R. Lohnes. 1971. Multivariate Data Analysis. John Wiley and Sons, New York. 364 pp.

Dyrness, C. T. 1963 Effects of burning on soil. Pages 291–304 *in:* Symposium of Forest Watershed Management. Oregon State University, Corvallis, Oregon. 355 pp.

Edington, J. M. 1966. Some observations on stream temperature Oikos 15: 265–273

Grier, C. C. 1975. Wildfire effects on nutrient distribution and leaching in a coniferous ecosystem. Can. J. For. Res. 5: 599–607.

Helvey, J. D. 1972. First-year effects of wildfire on water yield and stream temperature in northcentral Washington. Pages 308–312 *in:* National Symposium on Watersheds in Transition. U.S. Forest Service.

Hynes, H. B. N. 1970. The ecology of running waters. Univ. of Toronto Press. 555 pp.

McColl, J. G., and D. F. Grigal. 1975. Forest fire: effects on phosphorus movement to lakes. Science 188: 1109–1111.

Needham, P. R., and R. L. Usinger. 1956. Variability in the microfauna of a single riffle in Prosser Creek, California, as indicated by the Surber sampler. Hilgardia 24: 383–409.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. Statistical package for the social sciences. McGraw-Hill, New York. 675 pp.

Pase, C. P., and P. A. Ingebo. 1965. Burned chapparal to grass: early effects on water and sediment yields from two granitic soil watersheds in Arizona. Arizona Watershed Symposium, Sept. 22, 1965, Tempe, Arizona. U.S. Forest Service Reprint.

Robins, C. R., and R. W. Crawford. 1954. A short accurate method for estimating the volume of stream flow. J. Wildlife Manage. 18(3): 366–369.

Slack, K. V., R. C. Averett, P. E. Greeson, and R. G. Lipscomb. 1973. Techniques of water resources investigations of the United States Geological Survey. Chap. A4: book 5. 165 pp.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W.H. Freeman, San Francisco. 776 pp.

Surber, E. W. 1936. Rainbow trout and bottom fauna production in one mile of stream. Trans. Amer. Fish, Soc. 66: 193–202.

Tiedemann, A. R., and J. D. Helvey. 1973. Nutrient ion losses in streamflow after fire and fertilization in eastern Washington. Bull. Ecol. Soc. Amer. 54(1): 20.

U.S. National Park Service. 1975. Environmental assessment natural fire management plan, Yellowstone National Park. U.S. National Park Service Report. 41 pp.

———. 1976. The natural role of fire: a fire management plan. U.S. National Park Service Report. 26 pp.

Whitton, B. A. 1975. Algae. Pages 81–105 *in:* B. A. Whitton (ed.). River ecology. Univ. of Calif. Press, Berkeley. 725 pp.

Wright, R. F. 1976. The impact of forest fire on the nutrient influxes to small lakes in northeastern Minnesota. Ecology 57: 649–663

Calif. Fish and Game 65(4): 239–255 79

AN EVALUATION OF REARING FALL-RUN CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*, TO YEARLINGS AT FEATHER RIVER HATCHERY, WITH A COMPARISON OF RETURNS FROM HATCHERY AND DOWNSTREAM RELEASES [1]

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Fall-run chinook salmon, *Oncorhynchus tshawytscha,* were reared to yearlings ($\overline{wt}$ = 58 g) at Feather River Salmon and Steelhead Hatchery, and released in equal numbers at the hatchery and 225 km downstream in the lower Sacramento River near Rio Vista. Combined returns to the fisheries and spawning stocks were 7.5%: 6.1% to the fisheries and 1.4% to the spawning stocks. Yearlings released at the hatchery contributed more to the fisheries and spawning stocks (8.3%), with considerably less straying from the natal stream, than those released near Rio Vista (6.6%). When compared with returns from fingerling salmon ($\overline{wt}$ = 5 g), yearlings released at the hatchery contributed 12 times more to the fisheries. Based on minimum contributions to the fisheries and spawning stocks of all marked yearlings of the three brood years released, the benefit/cost ratio was 18.0:1.

INTRODUCTION

Studies with fall-run chinook salmon fingerlings in the Sacramento River system during the past two decades by the California Department of Fish and Game (CDFG) have demonstrated that hatchery releases of advanced fingerlings weighing 5 g contribute more adults to the fisheries and spawning stocks than do releases of fingerlings weighing 0.5 g (CDFG, unpublished data). Studies with advanced fingerlings have also shown that if they are released in the lower Sacramento River rather than at the hatcheries, many of the losses that occur during seaward migration are eliminated, resulting in greater returns to the fisheries and spawning stocks. Rearing as many chinook salmon fingerlings as egg supplies, space, and budgets permit to a minimum size of 5 g prior to release is now a standard procedure at Federal and State salmon and steelhead hatcheries on the Sacramento River System.

The Department of Fish and Game initiated a study in 1957 to find out if even greater returns to the fisheries and spawning stocks could be obtained by releasing chinook salmon as yearlings. In spring 1957 fall-run chinook salmon yearlings ($\overline{wt}$ = 56 g) were marked and released in the American River at Nimbus Salmon and Steelhead Hatchery. Total adult returns to the hatchery from the yearlings were about 34 times greater than average adult returns from advanced fingerlings

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(Warner, Fry, and Culver 1961). However, returns to the ocean commercial fishery were negligible, presumably because most of these fish matured in their third year at a smaller average size. Consequently, most reached the 66-cm commercial size limit later than others of the same year class and were available to the fishery for only a short period. Because of the excellent returns to the hatchery and spawning stocks, it was concluded that releasing yearlings might enable hatcheries to build up the run in a particular stream without going elsewhere for eggs.

In 1969, a second evaluation of rearing fall-run chinook salmon to yearlings was initiated by the Department of Fish and Game, this time with Feather River stock. It was also decided to determine at the same time if releasing yearlings in the lower Sacramento River, rather than at the Department's Feather River Salmon and Steelhead Hatchery, would further increase adult returns to the fisheries and spawning stocks, as it does with fingerlings.

This report of the second evaluation describes a study of returns of marked fall-run chinook salmon from three brood years (BY) reared to yearlings at Feather River Hatchery and released at two sites, plus a discussion of the economic feasibility and benefit/cost ratio of yearling releases.

METHODS

Evaluation Techniques

Fall-run salmon fingerlings from the 1967, 1969, and 1970 BY's were reared at Feather River Hatchery, Butte County (Figure 1), for approximately 1 year. The yearlings from each of the three brood years were then divided into two nearly equal lots and given separate identifying marks. One lot was released at the Hatchery and the other near Rio Vista. Salmon from the 1967 BY were marked by clipping two fins, while the 1969 and 1970 BY fish were marked by excising two fins plus inserting color-coded wire nose tags (Jefferts, Bergman, and Fiscus 1963). Salmon from the 1968 BY were not used in this study because of large losses they suffered in the hatchery during spring from the viral disease, infectious hematopoietic necrosis, often referred to in California as Sacramento River Chinook Disease.

The evaluation is based on estimates of the contribution of marked salmon released as yearlings to the ocean commercial and sport fisheries of California, Oregon, and Washington; the Sacramento River system sport fishery; the Sacramento-San Joaquin River system salmon spawning populations; plus the actual numbers of marked fish that returned to Sacramento River system fish hatcheries. Differences between returns from the two planting sites were evaluated by Chi-square. These returns were then compared with returns of salmon released as 5 g fingerlings.

Because of the differences in the numbers released from the three BY's, evaluation of return differences between BY's and the overall evaluation are based on the percentage returns and the average percentage returns for the three BY's.

Economic benefit/cost ratios were calculated based on the costs to produce the marked yearlings and the value of the marked fish caught.

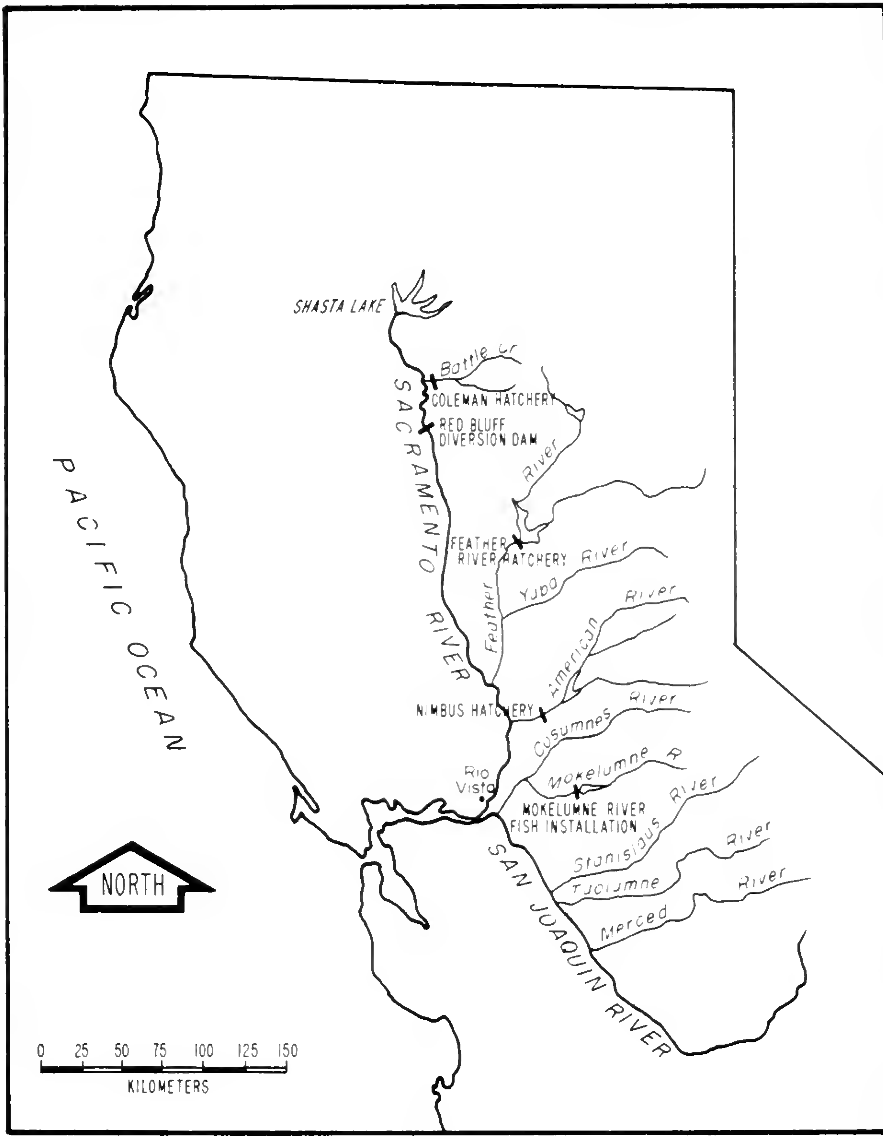

FIGURE 1. Sacramento-San Joaquin River System, showing marked salmon release sites and fresh-water recovery areas.

Marking and Releasing Study Fish

During 1969, 1971, and 1972, we released 266,790 marked salmon: 136,545 in the Feather River at or near Feather River Hatchery, and 130,245 in the Sacramento River at Bryant's Marina, near Rio Vista (Figure 1, Table 1). They ranged in average size from 38 g (12/lb) to 76 g (6/lb).

TABLE 1. Planting Summary, Yearling Chinook Salmon Study

Brood year	*Mark*		*Average size (g)*	*Date released*	*Number released*	
	Fin clip	*Nose tag*			*Feather River* *	*Rio Vista* +
1967	Ad-An	–	38	1/28–30/69		50,400
	Ad-RP	–	38	1/31/69	56,400	
1969	An-LP	Yellow	60	2/16–18/71		20,025
	An-LP	Blue	60	2/17/71	20,625	
1970	An-LP	Green	76	2/1–2/72	29,760	
	An-LP	Brown	76	2/1–2/72	29,760	
	An-LP	Red	76	2/3–4, 9–10/72		29,910
	An-LP	Pink	76	2/3–4, 9–10/72		29,910
TOTALS			Average 58		136,545	130,245

* 1967 and 1969 BY fish were released at Feather River Salmon and Steelhead Hatchery; 1970 BY fish were released at Vance Avenue in Oroville, approximately 3 km downstream from the hatchery.
+ Sacramento River near Bryant's Marina, approximately 10 km downstream from Rio Vista.

Driving distance between the hatchery and the Rio Vista planting site was 201 km and took about 3 hours for a loaded planting truck. Stream distance, via primary channels, was about 225 km.

Fin-clipping of the 1967 BY fish started on 4 December 1968. On 17 December, the marking was halted temporarily because symptoms of incipient parr-smolt transformation appeared, i.e., loosening of scales. This resulted in exfoliation when the fish were handled during the marking process. The marking was resumed on 20 January when the transformation symptoms subsided, and was completed on 27 January 1969.

The 1969 BY yearlings were the first salmon to be marked in California with nose tags. In addition to the nose tags, the 1969 and 1970 BY salmon were marked by removing the anal and left pectoral fins. As in the first year, the fin-clipping was interrupted by the parr-smolt transformation. Marking of the 1969 and 1970 BYs was completed in November 1970 and December 1971, respectively, and the nose tagging of each year-class was accomplished the following January and February.

Estimating Ocean Returns of Marked Salmon

State laws in California, Oregon, and Washington require that poundages from all salmon sold be recorded. California applies a modified Hartley-Ross ratio estimator (Abramson and Jensen 1963) to the landing receipts and data obtained through a stratified port sampling system to obtain estimates of species landed by number and weight, plus marked fish landed. Total mark recovery estimates are compiled by the Regional Mark Processing Center for Pacific Coast States, operated by the Oregon Department of Fish and Wildlife.

Procedures used by the three states for sampling the ocean sport fishery are described by Wendler (1960). California uses logs from commercial passenger fishing boats (partyboats) combined with interviews of skiff fishermen (Jensen and Swartzell 1967; Lesh 1977); Oregon utilizes a punch card reporting system, coupled with Coast Guard counts of fishing boats; Washington combines a punch card system with Coast Guard counts, fishermen interviews, and boathouse reports.

Estimating Freshwater Returns of Marked Salmon

The numbers of marked salmon which returned to spawn in California's Central Valley include those which enter hatcheries plus those which spawn naturally or are caught by fishermen. The number of marked salmon reported at hatcheries is considered accurate because every salmon is examined for marks. Other estimates are based upon sampling a portion of the catch or run and chances for error are considerable. This is particularly true when estimating contributions to natural spawning. Because of difficulties in recognizing marked salmon during salmon spawning surveys (due to carcass deterioration), the number of marked salmon which spawn naturally can be greatly underestimated. Freshwater return estimates, therefore, are minimal and can be highly variable, precluding their use in exacting analyses.

Because the American River spawning stock surveys from 1969 through 1974 failed to record the occurrence of marks, it was necessary to use an alternate method to estimate the number of marked salmon which spawned in the American River. This estimate was developed by multiplying the estimated total spawning population by the proportion of marked Feather River salmon which entered Nimbus Hatchery (Central Valley Spawning Stock Reports and Nimbus Hatchery Annual Reports).

There is no chinook salmon spawning in the Sacramento River downstream from the mouth of the Feather River. Estimates of marked salmon which spawned above this point were calculated by multiplying the total estimates of salmon which spawned in the Sacramento River system upstream from the Feather River by the portion of fish observed at the trap at Red Bluff Diversion Dam which bore the appropriate marks.

Similarly, these marked/unmarked ratios were applied to the estimated total Sacramento River fall-run salmon sport catch (CDFG, unpublished data) to estimate the number of marked salmon caught by sportsmen.

On the Mokelumne River the marked fish counts are those which entered the Mokelumne River Fish Installation near the base of Camanche Dam. No marked salmon were seen during spawning surveys on the River.

Economic Benefit Calculation

The estimation of economic values of salmon is a complicated problem; results are often highly variable and, as a result, controversial. Some of the complexities are discussed in detail by Seckler (1966); Gordon, Chapman, and Bjornn (1973), and Wahle, Vreeland, and Lander (1974). Because of the difficulties inherent in attempting to accurately measure the economic contribution of yearling-release chinook salmon, we limited ourselves to a comparatively simple, conservative estimate which, when compared with cost estimates, would indicate whether or not this type of management is economically justified.

The fishery value of salmon which returned in this study is considered to be the sum of the commercial and sport fishery estimates. Accordingly, the value of the commercially-caught salmon was determined by multiplying the estimated catch by the price paid by the buyers, and the value of the sport catch was based on the estimated amount of money that fishermen spent to catch each fish.

Ocean commercial catches of chinook salmon are normally graded by the processor into three sizes at the dock: (i) small (<3.6 kg), (ii) medium (3.6–5.4 kg), and (iii) large (≥ 5.4 kg). Prices paid usually vary according to the grade, with lower prices being paid for smaller fish. Prices generally increase during the season, and price differences often exist between different ports. We assumed, when calculating average prices paid to fishermen, that all marked salmon landed as 3-year-olds were graded as small or medium, and that all those taken as 4 and 5-year-olds were graded as large. Price, weight, and grade figures were calculated by averaging the data from every twentieth California commercial field sampling sheet.

We assumed that a sport-caught salmon is worth at least the amount of money that an angler spends to catch it. An economic survey by the California Department of Fish and Game in 1953 indicated that the average daily expenditure by California salmon fishermen was $16 (Pelgen 1955). These expenses included transportation, food, lodging, services and supplies, equipment, and licenses. To update the 1953 expenditure figure to the period from 1969 through 1974, the 6 years when marked salmon were caught, it was multiplied by appropriate percentage changes derived from the increases in the average annual Consumer Price Index (CPI) for San Francisco and Oakland (United States Department of Labor, Bureau of Labor Statistics).

We also assumed that the daily cost of ocean salmon sport fishing in Oregon and Washington during 1953 was equal to that in California. Since the increase in the average CPI for San Francisco-Oakland of 87.5% between 1953 and 1974 was paralleled by changes in the Portland and Seattle CPI's of 81.2% and 80% respectively, we assumed that the daily cost of ocean sport salmon fishing in Oregon and Washington was, for practical purposes, equivalent to that of California.

Between 1953 and 1969, the average annual CPI for San Francisco-Oakland increased 43.1%. Likewise by 1969, the estimated average cost for a day's ocean sport salmon angling had increased to $22.90, and by 1974 to $30. The average catch per angler day during the period of marked salmon recovery was 0.8 fish (California Marine Fish Landing Bulletins); thus it took 1.25 days of fishing for each salmon landed. The value of each sport-caught salmon was therefore obtained by multiplying the average cost per angler day during the season it was caught by 1.25.

Fish production costs include all expenditures associated with egg taking, rearing, and planting. Costs attributed to fish marking or to capital investment at the hatchery are not included.

RESULTS

Ocean Returns of Marked Salmon

Commercial Fisheries

Estimated returns to the ocean commercial fisheries of California, Oregon, and Washington, ranged from 0.5 to 5.1% (Table 2). The unweighted mean return for the three broodyears was 3.5%.

TABLE 2. Estimated Ocean Commercial Fishery Returns of Marked Salmon

		Recovery location								
		From Rio Vista release				From Feather R. release				
Brood year	*Year recovered*	*Calif.*	*Ore.*	*Wash.*	*Total*	*Calif.*	*Ore.*	*Wash.*	*Total*	*Grand totals* *
	1969	0	0	0	0	0	0	0	0	
	1970	1,488	123	9	1,620	1,630	160	6	1,796	
1967	1971	522	5	15	542	1,199	14	20	1,233	
	1972	0	5	0	5	12	7	0	19	
BY Totals	Number	2,010	133	24	2,167	2,841	181	26	3,048	5,215 (903)
	Percent +	4.0	0.3	< 0.1	4.3	5.0	0.3	< 0.1	5.4	4.9
	1971	0	0	0	0	0	0	0	0	
	1972	635	0	0	635	737	0	0	737	
1969	1973	202	5	0	207	479	13	0	492	
	1974	7	0	0	7	0	0	0	0	
BY Totals	Number	844	5	0	894 ‡	1,216	13	0	1,229	2,078 (350)
	Percent +	4.2	< 0.1	0	4.2	5.9	0.1	0	6.0	5.1
	1972	0	0	0	0	0	0	0	0	
	1973	43	0	9	52	52	0	10	62	
1970	1974	242	17	0	259	251	19	0	270	
	1975	0	0	0	0	0	0	0	0	
BY Totals	Number	285	17	9	311	303	19	10	332	643 (80)
	Percent +	0.5	< 0.1	< 0.1	0.5	< 0.1	< 0.1	0.6	0.5	
Unweighted mean return (%)					3.0				4.0	3.5

* Number in parentheses indicates actual marked fish recovered
+ Calculated marks recovered divided by number released as yearlings
‡ Two of the 1969 BY salmon, released at Rio Vista, were also recovered in Alaska during 1974, but are not included in the table

The 1967 and 1969 BY salmon made substantial contributions to the ocean commercial fishery, returning, respectively, an estimated 5,215 (4.9%) and 2,078 (5.1%) of the total marked fish released at both sites. Over 90% were landed in California. Nearly 66% were caught as 3-year-olds, and 34% were caught as 4-year-olds.

The 1970 BY salmon contributed comparatively little to the commercial fisheries. Only 643 (0.5%) of the total marked fish released at both sites were estimated to have been caught by commercial trollers. In contrast with the 1967 and 1969 BY fish, only 15% of the 1970 BY salmon were landed as 3-year-olds, while 85% were caught as 4-year-olds.

A comparison of contributions to the ocean commercial fishery showed that yearlings released in the Feather River contributed at a rate 1.3 times those released near Rio Vista, with mean returns of 4.0%, and 3.0%, respectively.

Sport Fisheries

Estimated contributions to the ocean sport fisheries of California, Oregon, and Washington ranged from 0.3 to 5.0% (Table 3). The unweighted mean return for the three broodyears was 2.6%.

The 1967 and 1969 BY salmon made substantial contributions to the ocean sport fishery, as they did to the ocean commercial fishery, with an estimated 4,691 (3.2%) of the marked yearlings being landed. However, percentage returns for the 1969 BY salmon were about twice that of the 1967 BY fish.

The 1970 BY salmon contributed comparatively little to the ocean sport fisheries, as only 402 (0.3%) were caught.

Eighty-seven percent of the sport-caught salmon from all three brood years were landed as 3-year-olds and 12% as 4-year-olds. This pattern was fairly consistent for salmon from all brood years, and the dominance (85%) of the 1970 BY as 4-year-olds in the commercial catch was not evident in the sport catch. A comparison of returns from all three broodyears to the ocean sport fishery showed that yearlings released in the Feather River contributed at a rate 1.5 times those trucked to Rio Vista: 3.1% of those released at the hatchery and 2.1% of those released at Rio Vista.

Freshwater Returns of Marked Salmon

Estimated adult returns to the Sacramento-San Joaquin River system, including the freshwater sport catch, ranged from 0.6 to 2.0% (Table 4). The unweighted mean return for the three broodyears was 1.4%.

A comparison of returns to Central Valley streams from all three brood years showed that yearlings released at Rio Vista contributed more adult salmon than those released in the Feather River: 1.5% from Rio Vista compared to 1.2% from the Feather River. However, there was considerable straying from the parent stream by adults from the Rio Vista releases, with only 22% of the returning fish recovered in the Feather River. The majority (73%) were recovered in the American River, 3% in the Sacramento River, and 2% in the San Joaquin River system. In contrast, 90% of the returning adults from Feather River releases were recovered in the Feather River and 10% in the American River.

Thirty-six percent of the returning salmon from all three brood years were 2-year-olds; 63% were almost equally divided between 3- and 4-year-olds; 1% returned as 5-year-olds.

TABLE 3. Estimated Ocean Sport Fishery Returns of Marked Salmon

Brood year	Year recovered	From Rio Vista release: Calif.	Ore.	Wash.	Total	From Feather R. release: Calif.	Ore.	Wash.	Total	Grand totals *
	1969	28	0	0	28	12	0	0	12	
	1970	791	4	52	847	1,162	20	73	1,255	
1967	1971	212	3	5	220	276	4	12	292	
	1972	0	0	0	0	0	0	0	0	
BY totals	Number	1,031	7	57	1,095	1,450	24	85	1,559	2,654 (310)
	Percent +	2.0	<0.1	0.1	2.2	2.6	<0.1	0.2	2.8	2.5
	1971	4	0	0	4	7	0	0	7	
	1972	747	2	0	749	1,213	4	0	1,217	
1969	1973	24	0	0	24	36	0	0	36	
	1974	0	0	0	0	0	0	0	0	
BY totals	Number	775	2	0	777	1,256	4	0	1,260	2,037 (336)
	Percent +	3.8	<0.1	0	3.8	6.1	<0.1	0	6.1	5.0
	1972	0	0	0	0	0	0	0	0	
	1973	185	5	3	193	165	4	2	171	
1970	1974	9	0	10	19	9	0	10	19	
	1975	0	0	0	0	0	0	0	0	
BY totals	Number	194	5	13	212	174	4	12	190	402 (72)
	Percent +	0.3	<0.1	<0.1	0.4	0.3	<0.1	<0.1	0.3	0.3
Unweighted mean returns (%)					2.1				3.1	2.6

* Number in parentheses indicates actual marked fish recovered

\+ Calculated marks recovered divided by number released as yearlings.

TABLE 4. Estimated Freshwater Returns of Marked Salmon *

		Recovery Location										
		From Rio Vista release							From Feather River release			
Brood year	*Year recovered*	*Feather River*	*American River*	*Sacramento River*	*Mokelumne River*	*Stanislaus River*	*Tuolumne River*	*Total*	*Feather River*	*American River*	*Total*	*Grand Totals*
	1969	15(15)	432(28)	0	7(7)	12	6	472	48(35)	0	48	
	1970	107(95)	17(4)	0	1(1)	0	0	125	592(285)	0	592	
1967	1971	112(67)	162(34)	48	0	0	0	322	511(134)	10(2)	521	
	1972	3(3)	4(1)	8	0	0	0	15	35(7)	0	35	
BY Totals	Number	237(180)	615(67)	56+	8(8)	12	6	934	1,186(461)	10(2)	1,196	2,130
	Percent ‡	0.5	1.2	0.1	<0.1	<0.1	<0.1	1.8	2.1	<0.1	2.1	2.0
	1971	22(2)	193(29)	0	1(1)	0	0	216	148(88)	20(3)	168	
	1972	8(1)	131(24)	0	2(2)	0	0	141	39(12)	9(2)	48	
1969	1973	2	17(2)	0	0	0	0	19	8(3)	0	8	
	1974	0	0	0	0	0	0	0	0	0	0	
BY Totals	Number	32(3)	341(60)	–	3(3)	–	–	376	195(103)	29(5)	224	600
	Percent ‡	0.2	1.7	–	<0.1	–	–	1.9	0.9	0.1	1.1	1.5
	1972	42(7)	185(41)	0	0	0	0	227	55(19)	63(14)	118	
	1973	27(4)	60(7)	0	0	0	0	87	38(14)	26(3)	64	
1970	1974	48(7)	93(10)	0	0	0	0	141	64(21)	37(4)	101	
	1975	0	0	0	0	0	0	0	0	0	0	
BY Totals	Number	117(18)	338(58)	–	–	–	–	455	157(54)	126(21)	283	738
	Percent ‡	0.2	0.6	–	–	–	–	0.8	0.3	0.2	0.5	0.6
Unweighted mean returns (%)								1.5			1.2	1.4

* Actual marks recovered at hatcheries on the Feather, American, and Mokelumne rivers (shown in parentheses), plus estimated returns of marked fish from salmon spawning surveys on all rivers and Sacramento River sport fishery creel censuses.

+ Includes eight sport-caught salmon: seven in 1971 and one in 1972.

‡ Calculated marks recovered divided by number released as yearlings.

Summary of Ocean and Freshwater Returns of Marked Salmon

The estimated percent return of marked salmon from all fisheries plus the spawning stock contributions ranged from 1.4 to 13.2% (Table 5). The average for all broodyears and release sites was 7.5%.

TABLE 5. Summary of Estimated Ocean and Freshwater Percent Returns of Marked Salmon

Recovery Location	*Brood year* 1967	1969	1970	*Average*
Rio Vista release				
Ocean returns (total)	6.5	8.0	0.9	5.1
Commercial	4.3	4.2	0.5	3.0
Sport	2.2	3.8	0.4	2.1
Freshwater returns (total)	1.8	1.9	0.8	1.5
Feather River Hatchery	0.4	<0.1	<0.1	0.2
Nimbus Hatchery	0.1	0.3	0.1	0.2
Other	1.3	1.6	0.6	1.2
TOTAL	8.3	9.9	1.7	6.6
Feather River release				
Ocean returns (total)	8.2	12.1	0.9	7.1
Commercial	5.4	6.0	0.6	4.0
Sport	2.8	6.1	0.3	3.1
Freshwater returns (total)	2.1	1.1	0.5	1.2
Feather River Hatchery	0.8	0.5	0.1	0.5
Nimbus Hatchery	<0.1	<0.1	<0.1	<0.1
Other	1.3	0.6	0.3	0.7
TOTAL	10.3	13.2	1.4	8.3

ECONOMIC ANALYSIS

Yearling Salmon Production Costs

The cost of rearing fall-run chinook salmon to yearlings at Feather River Hatchery ranged from $0.77/kg for the 1969 BY to $3.57/kg for the 1967 BY (Table 6). This variation was due primarily to mortality differences during rearing. The average cost per fish was 6.1 cents.

Based on the cost per kilogram of all yearlings of each BY planted during the study period, the cost of the marked fish was $27,453 (Table 6). Because they were substantially larger (fewer fish per kg) than the average for all yearlings each year, the average cost of each marked yearling was greater, averaging 10.3 cents per fish.

Value of Marked Salmon Caught by Commercial Fishermen

The estimated total value of the 7,936 marked salmon, weighing 39,228.5 kg landed by ocean commercial fishermen in California, Oregon and Washington during the five seasons (1970–74) was $67,390.78 (Table 7); California's 94.5% share totaled $63,684.29. The total value includes $39,799.47 attributed to salmon released near the Hatchery and $27,591.31 for those released at Rio Vista.

TABLE 6. Yearling Fall-run Chinook Salmon Production Costs [a], Feather River Salmon and Steelhead Hatchery

	All yearlings				Marked yearlings				
Brood year	Number	$\overline{wt}$ (g)	Cost per kg ($)	Cost per fish ($)	Number	$\overline{wt}$ (g)	Total weight (kg)	Total cost ($)	Cost per fish ($)
1967	537,500	19	3.57 [b]	0.066	106,800	38	4,036	14,418	0.135
1969	654,150	43	0.77 [c]	0.034	40,650	60	2,458	1,897	0.047
1970	903,190	64	1.23 [d]	0.079	119,340	76	9,022	11,138	0.093
TOTALS [e]	2,094,840	Av. 46		Av. 0.061	266,790	Av. 58	15,515	27,453	Av. 0.103

[a] Does not include marking costs.
[b] Schafer 1970.
[c] Bruley 1972.
[d] Bruley 1973.
[e] Data originally collected in English units and converted to metric for publication; some calculations, therefore, cannot be duplicated exactly from the data presented

TABLE 7. Estimated Value of Marked Salmon Caught by Commercial Fishermen [a]

Yearling releases		Recoveries, Weights and Values							
Brood year	Location	Year	Number	Grade	Average weight (kg)	Total weight (kg)	per kg ($)	Value ($)	Brood year values ($)
1967	Rio Vista	1970	360	Small	3.18	1,142.86	1.21	1,386.00	
			1,260	Medium	4.22	5,314.29	1.52	8,085.42	
		1971	542	Large	8.26	4,473.65	1.76	7,891.52	
		1972	5	Large	10.89	54.42	1.96	106.80	
	TOTALS		2,167		Av. 5.07	10,985.22	Av. 1.59	17,469.74	
	Feather R.	1970	395	Small	3.22	1,271.88	1.21	1,542.48	
			1,401	Medium	3.63	5,083.00	1.52	7,733.52	
		1971	1,233	Large	7.57	9,338.37	1.76	16,472.88	
		1972	19	Large	9.98	189.57	1.96	372.02	
	TOTALS		3,048		Av. 5.21	15,882.82	Av. 1.65	26,120.90	43,590.64

TABLE 7.—*Continued*

1969	Rio Vista	1972	140	Small	3.18	444.44	1.32	588.00	
			494	Medium	3.90	1,926.71	1.59	3,058.85	
		1973	208	Large	6.76	1,405.53	2.31	3,254.16	
		1974	7	Large	10.16	71.11	2.43	172.48	
	TOTALS		849		Av 4.53	3,847.79	Av. 1.83	7,073.49	
	Feather R	1972	162	Small	3.18	514.29	1.32	680.40	
			716	Medium	3.90	2,792.56	1.59	4,433.47	
		1973	351	Large	6.53	2,292.24	2.31	5,307.12	
		1974	0						
	TOTALS		1,229		Av 4.56	5,599.09	Av 1.85	10,420.99	17,494.48
1970	Rio Vista	1973	11	Small	3.18	32.92	1.65	57.75	
			203	Medium	3.90	791.75	1.98	1,571.22	
		1974	97	Large	6.03	585.08	2.43	1,419.11	
	TOTALS		311		Av 4.56	1,411.75	Av 2.16	3,048.08	
	Feather R	1973	14	Small	3.18	44.44	1.65	73.50	
			204	Medium	3.90	795.65	1.98	1,578.96	
		1974	114	Large	5.81	661.77	2.43	1,605.12	
	TOTALS		332		Av 4.52	1,501.81	Av. 2.16	3,257.58	6,305.66
GRAND TOTALS			7,936		Av 4.94	39,228.53	Av 1.72		67,390.78

[a] Data originally collected in English units and converted to metric for publication, some calculations, therefore, cannot be duplicated exactly from the data presented

TABLE 8. Estimated Value of Marked Salmon Caught by Sport Fishermen

		Angler expense		Number and value * of salmon recovered					
				Rio Vista release		Feather R. release		Totals	
Brood year	Year of return	Per Angler day	Per fish †	Number	Value ($)	Number	Value ($)	Number	Value ($)
1967	1969	22.90	28.63	28	802	12	344	40	1,146
	1970	24.06	30.08	847	25,478	1,255	37,750	2,102	63,228
	1971	24.96	31.20	227	7,082	292	9,110	519	16,192
	1972	25.82	32.28	1	32	0	0	1	32
Totals				1,103	33,394	1,559	47,204	2,662	80,598
1969	1971	24.96	31.20	4	125	7	218	11	343
	1972	25.82	32.28	749	24,178	1,217	39,285	1,966	63,463
	1973	27.33	34.16	24	820	36	1,230	60	2,050
Totals				777	25,123	1,260	40,733	2,037	65,856
1970	1973	27.33	34.16	193	6,593	171	5,841	364	12,434
	1974	30.00	37.50	19	713	19	713	38	1,426
Totals				212	7,306	190	6,554	402	13,860
GRAND TOTALS				2,092 ‡	65,823	3,009	94,491	5,101	160,314

* Rounded to nearest dollar.
† Cost per angler day x 1.25.
‡ Eight adult salmon were caught in the Sacramento River (seven in 1971 and one in 1972); the remainder were caught in the ocean sport fishery.

Value of Marked Salmon Caught by Sport Fishermen

Using the estimated amount of money spent by a sport fisherman to catch salmon as an indication of their value, the 5,101 marked fish caught by sport anglers between 1969 and 1974 had a total value of $160,314 (Table 8). Those released at Rio Vista contributed 2,092 salmon to the catch for a value of $65,823; those released in the Feather River contributed 3,009 fish, valued at $94,491.

Benefit/Cost Ratio

The benefit/cost ratio for planting yearling chinook salmon ranged from 1.8:1 to 53.1:1 (Table 9). The overall unweighted benefit/cost ratio was 18.0:1.

TABLE 9. Calculation of Benefit/Cost Ratio for Marked Yearling-release Salmon

Brood year	*Planting site*	*Value ($)*	*Cost ($)*	*Benefit/cost ratio*
1967	Rio Vista	50,864	6,804	7.5:1
	Feather River	73,325	7,614	9.6:1
Totals		124,189	14,418	8.6:1
1969	Rio Vista	32,196	934	34.1:1
	Feather River	51,154	963	53.1:1
Totals		83,350	1,897	43.9:1
1970	Rio Vista	10,354	5,555	1.9:1
	Feather River	9,812	5,583	1.8:1
Totals		20,166	11,138	1.8:1
Unweighted mean ratio				18.0:1

Data were not available to accurately separate hauling costs from total fish production costs at Feather River Hatchery during the study period. Since fish production costs included expenses associated with hauling, the costs used to calculate benefit/cost ratios are assumed to be slightly low for the Rio Vista releases and slightly high for Hatchery releases. In effect, the actual benefit/cost ratio for releasing yearlings at the Hatchery would be more favorable than indicated, and that for releasing at Rio Vista less favorable.

DISCUSSION AND CONCLUSIONS

The overall excellent results of this study are partially clouded by the poor contribution of the 1970 BY. (A review of the history of the 1970 BY salmon at the hatchery, as well as conditions in the Feather River and Sacramento-San Joaquin Delta during the release and recovery periods, failed to shed any light on their comparatively poor fishery contributions or the shift in age class pattern.) Nevertheless, total returns to the fisheries of marked yearling salmon were impressive: 5.1% of those released in the Sacramento River at Rio Vista and 7.1% of those released in the Feather River near the hatchery. When compared with returns from salmon released as fingerlings they are even more impressive. For example, fishery returns from 1961–1971 releases of 3.5 million marked fingerlings ($\overline{wt} = 5$ g) reared at Coleman and Nimbus Hatcheries averaged 1.0% for those released at Rio Vista and 0.5% for those released at the hatcheries (CDFG, unpublished data). The fishery contribution rate of yearling-release salmon was therefore 5.1 times greater for those released at Rio Vista and 14.2

times greater for those released at the hatchery than that from fingerling-release fish.

Salmon released as yearlings also made substantial contributions to the spawning stocks, as a minimum of 1.4% of those released at Rio Vista and 1.2% of those released in the Feather River returned to spawn. Minimum estimated freshwater returns from the previously mentioned 3.5 million fingerlings averaged 0.08% for those released at Rio Vista and 0.06% for those released at the hatcheries. Total freshwater returns from fingerlings released at Coleman and Nimbus hatcheries approximate the 0.07% average (range 0.00–0.47%) returns from 34 lots of fall-run chinook salmon released as fingerlings from several hatcheries operated by the California Department of Fish and Game, U. S. Fish and Wildlife Service, and Washington Department of Fisheries over a period of years (Warner, Fry, and Culver 1961). The spawning stock contribution rate of returning yearling-release salmon was therefore 18.8 times greater for Rio Vista releases and from 17.1–20.0 times greater for Feather River releases than the average freshwater returns from fingerling releases.

Although significantly greater returns to the fisheries and spawning stocks result from releasing yearling salmon in the Feather River than from Rio Vista releases ($p < 0.01$), predation on naturally-produced fingerlings by these yearlings could be considerable. In January and February 1972, following the release of 532,000 1970 BY fall-run chinook salmon yearlings in the Feather River, studies by the Department indicated that as many as 7.5 million naturally-produced salmon fingerlings were eaten by the yearlings (Richard E. Painter, Associate Fishery Biologist, CDFG, and Lynn H. Wixom, Assistant Fishery Biologist, CDFG; pers. commun.). Based on an estimated contribution rate of 0.17% for salmon produced naturally in the Sacramento River system (CDFG, unpublished data), this loss could result in a reduced catch of 12,750 in the ocean fishery. The yearlings did not migrate out of the Feather River immediately, but stayed in the upper river where sampling indicated they averaged 1.3 salmon fingerlings per stomach. Short duration flushing flows, intended to induce outmigration, had no noticeable effect upon the distribution and concentration of the yearlings. Consequently, while trucking yearling salmon from Feather River Hatchery to Rio Vista is not justified on the basis of increasing returns, it may be desirable to stock yearlings in the Sacramento or lower Feather rivers in order to reduce predation of the yearlings on naturally produced fingerlings.

Although releasing yearlings near Rio Vista resulted in considerable straying of returning adults, primarily to the American River, sufficient salmon returned to Feather River Hatchery to continue a self-sustaining program.

SUMMARY

1. A total of 266,790 yearling fall-run chinook salmon was raised, marked, and released from Feather River Salmon and Steelhead Hatchery: 106,800 from the 1967 BY, 40,650 from the 1969 BY, and 119,340 from the 1970 BY. These were stocked in January 1969, February 1971, and February 1972, respectively. Approximately half of the fish (136,545), were planted in the Feather River near the hatchery; the remaining 130,245 were planted in the Sacramento River near Rio Vista.
2. The average total percentage return was 8.3% from the Feather River release and 6.6% from the Rio Vista release.

3. An estimated 4,609 salmon from the Feather River release (4.0% average return) and 3,327 from the Rio Vista release (3.0% average return) were caught in the commercial fishery, with an estimated, combined value of $67,390.
4. An additional 3,009 salmon from the Feather River release (3.1%, average return) and 2,084 from the Rio Vista release (2.1% average return) were caught in the sport fisheries (only eight from fresh water) with a combined estimated value of $160,314.
5. A minimum estimate of 1,703 salmon from the Feather River release (1.2% average return) and 1,765 (including the eight sport-caught fish) from the Rio Vista release (1.5% average return) returned as adults to fresh water. We did not attempt to place a value on these salmon.
6. The cost of the yearling salmon used in this program was estimated to be $27,453. This does not include marking costs.
7. The economic benefit/cost ratio was calculated to be 18.0:1.
8. Although the fish planted in the Feather River provided a greater return than did those planted at Rio Vista, they ate considerable numbers of naturally-produced fingerling salmon, at least partially offsetting their greater returns.
9. Salmon released in the Feather River returned primarily to the parent stream; those released at Rio Vista returned to many different streams in the drainage, with the greatest number of returns to the American River.

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REFERENCES

Abramson, N. J., and P.T. Jensen, 1963. Statistical methods for estimating California salmon landings. Pac. Mar. Fish. Comm. Bull. 6:6–10.

Bruley, G. K. 1972. California trout, salmon, and warmwater fish production costs, 1970–71. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 72(5).

———. 1973. California trout, salmon, and warmwater fish production costs, 1971–72. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 73(5).

Gordon, D., D. W. Chapman, and T. C. Bjornn. 1973. Economic evaluation of sport fisheries—what do they mean? Amer. Fish Soc., Trans. 102(2):293–311.

Jefferts, K. B., P. K. Bergman, and H. F. Fiscus. 1963. A coded-wire identification system for macro-organisms. Nature 198(4879):460–462.

Lesh, E. W., Jr. 1977. A stratified random sampling program used to estimate landings in the northern California ocean skiff recreational salmon fishery. Calif. Dept. Fish and Game, Anad. Fish. Br. Admin. Rep. 77(2).

Pelgen, D. E. 1955. Economic values of striped bass, salmon and steelhead sport fishing in California. Calif. Fish Game, 41(1):5–18.

Schafer, W. E. 1970. California trout, salmon and warmwater fish production costs, 1968–69. Calif. Dept. Fish and Game, Inland Fish. Admin. Rep. 70(1).

Seckler, D. W. 1966. On the uses and abuses of economic science in evaluating public outdoor recreation. Land Economics 42(4):485–494.

Wahle, R. J., R. R. Vreeland, and R. H. Lander. 1974. Bioeconomic contribution of Columbia River hatchery coho salmon, 1965 and 1966 broods, to the Pacific salmon fisheries. Natl. Ocean. and Atmos. Admin., Fish. Bull. 72(1):139–169.

Warner, G. H., D. H. Fry, Jr., and A. N. Culver. 1961. History of yearling king salmon marked and released at Nimbus Hatchery. Calif. Fish Game 47(4):343–355.

Wendler, H. O. 1960. The importance of the ocean sport fishery to the ocean catch of salmon in the states of Washington, Oregon, and California. Calif. Fish Game 46(3):291–300.

Calif. Fish and Game 65(4): 256–264 79

NOTES ON SOME UNCOMMON DEEP-SEA FISHES FROM THE MONTEREY BAY AREA, CALIFORNIA [1]

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Monterey Bay has been an important source of deep-sea animals for scientific study. Recent deep water sampling cruises in the vicinity of the Monterey Canyon and the adjacent continental slope have resulted in the capture of several unrecorded species. Fishes generally living below 200 m have had the greatest faunal increase. We report 19 new records among the 110 species listed in this work. Seven species were of particular interest because considerable range extension or rarity warranted discussion. They are i) *Somniosus pacificus*; ii) *Apristurus kampae*; iii) *Careproctus gilberti*; iv) *Elassodiscus caudatus*; v) *Paraliparis albescens*; vi) *Allocyttus folletti*; vii) *Lycenchelys camchatica*.

INTRODUCTION

Uncommon deep-sea fishes often have been taken in Monterey Bay, California, by commercial fishermen and scientific collectors. Some have even been found on beaches around the Bay. One important reason for this is that the Bay is cut by a submarine canyon which is nearly 3,600 m deep near its entrance. This canyon allows deep-living organisms to come close to shore where they are apt to be caught or washed ashore during storms or other unusual conditions (Aughtry 1953; Fast 1957; Follett 1970). Secondly, Monterey Bay has several fisheries that, during their normal activities, also capture unusual fishes. Fishermen often have been cooperative in making specimens available for scientific study. Finally, the Bay has hosted numerous collecting expeditions, such as that of the ALBATROSS (Gilbert 1899, 1915) and has numerous marine facilities, such as the U. S. Naval Postgraduate School, Hopkins Marine Station of Stanford University, an office and laboratory of the California Department of Fish and Game (DFG), and Moss Landing Marine Laboratories (MLML). The activites of these facilities have aided in recording occurrences of uncommon deep-sea animals (Thompson 1920, 1921; Sette 1923; Phillips 1932, 1952, 1961*a*, 1961*b*, 1967; Bolin 1937, 1940; Gregory 1969; Anderson and Cailliet 1975; Cailliet and Anderson 1975; Cailliet and Lea 1977).

Because the fish fauna of Monterey Bay is relatively well known (Kukowski, 1972; Cailliet et al. 1977), it is important to add significant knowledge of the fauna to keep records up to date. Also, because Monterey Bay has such deep water so close to shore, our work has centered on the canyon, resulting in numerous additions to the fish fauna and a more reasonable estimation for the abundance of uncommon species.

In this study we update the Monterey Bay species list (Kukowski 1972), redescribe a species, and report depth and range extensions for some fishes which normally live deeper than 200 m.

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MATERIALS AND METHODS

Deep water sampling cruises by personnel of MLML and accidental captures by fishermen have produced the material reported here. Mesopelagic species were taken chiefly by midwater trawls (McCosker and Anderson 1976, Anderson 1977) and from albacore stomachs saved by local fishermen. Benthic species were captured primarily using sablefish traps (Osada and Cailliet 1975); miscellaneous collections were taken by beam trawl aboard the USNS DE STEIGUER, and by otter trawls, longlines, and gill net sets (Cailliet, unpub. data). Kliever (1976), in his study of the persimmon eelpout, *Maynea californica,* used square habitat traps baited with kelp and surfgrass to catch other species.

Specimens examined in this study are deposited in the collections of California Academy of Sciences (CAS), Scripps Institution of Oceanography (SIO), National Museum of Natural History (USNM), and MLML.

RESULTS

In all, 110 species of deep-living fishes belonging to 41 familes are reported (Table 1). Of these, most were captured in bottom trawls (57) and midwater trawls (57). Several species were taken by sablefish traps (21), gill nets (11), longlines (8), albacore stomachs (4), habitat traps (5), and beach casts(2). Fishes were listed from albacore stomachs when they were known to have been caught near the Bay's entrance, and beach casts for those whose known daytime depth preference is below 200 m. Of special interest are the occurrences of seven of these species, detailed below.

TABLE 1: List of fishes captured in the Monterey Bay area below 200 m, 1972–1977, including those for which no exact data is known but whose daytime depth preference is normally below 200 m. Gear abbreviations are: AS—albacore stomachs; BT—bottom trawl; GN—gill net; HT—habitat trap; LL longline; MT—midwater trawl; ST—sablefish traps. Species with asterisks have not been reported previously.

Species	*Gear employed*
Myxinidae	
Eptatretus deani	LL, ST, BT
Eptatretus stoutii	LL, ST, BT
Hexanchidae	
Hexanchus griseus	GN
Squalidae	
Echinorhinus cookei	GN, ST
Somniosus pacificus *	ST
Squalus acanthias	GN, LL, ST, BT
Scyliorhinidae	
Apristurus brunneus	BT, MT
Apristurus kampae *	BT
Parmaturus xaniurus	MT, GN
Rajidae	
Raja inornata	BT
Raja kincaidi	BT
Raja rhina	BT
Raja trachura *	BT
Alepocephalidae	
Alepocephalus tenebrosus	LL, ST, MT
Talismania bifurcata *	MT
Searsiidae	
Pellisolus facilis *	MT
Sagamichthys abei	MT
Gonostomatidae	
Cyclothone acclinidens	MT
Cyclothone pallida	MT
Cyclothone signata	MT
Photichthyidae	
Vinciguerria lucetia	MT
Sternoptychidae	
Argyropelecus affinis	MT
Argyropelecus lychnus	MT
Argyropelecus sladeni	MT, BT
Danaphos oculatus *	MT
Sternoptyx diaphana	MT
Sternoptyx obscura *	MT

Chimaeridae	
Hydrolagus colliei	GN, BT
Argentinidae	
Argentina sialis	BT
Bathylagidae	
Bathylagus milleri	MT
Bathylagus pacificus	MT
Bathylagus wesethi	MT
Leuroglossus stilbius	MT
Bathylychnops exilis *	MT
Alepisauridae	
Alepisaurus ferox	beach casts
Notosudidae	
Scopelosaurus harryi *	MT
Paralepididae	
Lestidiops ringens *	AS, MT
Myctophidae	
Diaphus theta	MT
Lampanyctus regalis	MT
Lampanyctus ritteri	MT
Protomyctophum crockeri	MT
Stenobrachius leucopsarus	MT, BT
Symbolophorus californiensis	MT, AS
Tarletonbeania crenularis	MT, AS, beach casts
Batrachoididae	
Porichthys notatus	MT, BT, GN
Gadidae	
Gadus macrocephalus	BT
Merlucciidae	
Merluccius productus	MT, BT, ST, GN
Moridae	
Antimora microlepis	ST, BT
Physiculus rastrelliger *	BT
Macrouridae	
Albatrossia pectoralis	BT, ST
Coryphaenoides acrolepis	LL, BT, ST
Nezumia stelgiodolepis *	BT
Scomberesocidae	
Cololabis saira	MT
Melamphaidae	
Poromitra crassiceps	MT
Scopelogadus mizolepis bispinosus	MT
Trichiuridae	
Aphanopus carbo *	BT
Chauliodontidae	
Chauliodus macouni	MT
Malacosteidae	
Aristostomias scintillans	MT
Idiacanthidae	
Idiacanthus antrostomus	MT
Melanostomiatidae	
Bathophilus flemingi *	MT
Tactostoma macropus	MT
Trachipteridae	
Trachipterus altivelis	MT, AS
Scorpaenidae	
Sebastes babcocki	BT
Sebastes diploproa	BT, GN
Sebastes elongatus	BT, GN
Sebastes levis	ST
Sebastes melanostomus	ST
Sebastes paucispinis	BT, ST, GN, LL
Sebastes rosenblatti	ST
Sebastes saxicola	BT
Sebastes zacentrus	BT
Sebastolobus alascanus	BT, MT, ST
Sebastolobus altivelis	BT, MT
Anoplopomatidae	
Anoplopoma fimbria	BT, LL, ST
Hexagrammidae	
Ophiodon elongatus	BT, ST, GN, LL
Cottidae	
Icelinus filamentosus	BT
Icelinus oculatus *	BT
Icelinus tenuis	BT
Psychrolutes phrictus	ST
Radulinus asprellus	BT
Agonidae	
Bathyagonus pentacanthus	BT, MT
Xeneretmus latifrons	BT, MT
Xeneretmus leiops	BT
Xeneretmus triacanthus	BT
Liparididae	
Careproctus sp. cf *C. melanurus*	BT
Careproctus gilberti *	MT
Elassodiscus caudatus	BT
Liparis fucensis	BT, HT
Lipariscus nanus	MT
Nectoliparis pelagicus	MT
Paraliparis albescens	BT, MT, HT
Paraliparis cephalus	BT
Paraliparis rosaceus	ST

Oreosomatidae	
*Allocyttus folletti**	BT
Bythitidae	
*Cataetyx rubrirostris**	MT
Zoarcidae	
Aprodon cortezianus	BT
Bothrocara brunneum	BT, ST
*Lycenchelys camchatica**	BT
Lycodapus dermatinus	BT, MT
Lycodapus fierasfer	BT
Lycodapus mandibularis	BT, MT, HT
Lycodes diapterus	BT
Lycodopsis pacifica	BT
Maynea californica	BT, HT
Melanostigma pammelas	MT
Bothidae	
Citharichthys sordidus	BT, MT, HT
Citharichthys stigmaeus	MT
Pleuronectidae	
Embassichthys bathybius	BT
Glyptocephalus zachirus	BT, MT
Microstomus pacificus	BT, MT, ST

Somniosus pacificus Bigelow and Schroeder, 1944

Six young Pacific sleeper sharks, ranging in length from 92 to 142 cm, were landed in Moss Landing by sablefish trappers. According to Osada and Cailliet (1975), catches of this species by sablefish trappers in Monterey Bay are not uncommon. Fishermen have reported much gear destruction, presumably by this species. One large specimen (at least 4.5 m) was brought to the surface by Rold Bros., Inc. in northern Monterey Bay but could not be landed. To our knowledge, the southernmost record of a Pacific sleeper shark is that of a specimen photographed off Baja California (lat 30° 53.0′ N, long 116° 45.0′ W) with baited cameras by the Marine Life Research Group of SIO in 2,008 m.

Apristurus kampae Taylor, 1972

A single longnose cat shark was taken in a commercial otter trawl in about 640–730 m off Cypress Point, Monterey County on 19 May 1977. Previously, the northern limit of its range was off San Diego (Taylor 1972). The specimen, an immature female 439 mm TL, is deposited in the Ichthyology Collection of MLML [DB-52 (6324)].

Careproctus gilberti Burke, 1912

A single smalldisk snailfish (CAS 29948, 75 mm SL) was collected in a 1.3 m zooplankton net fished from the surface to within 50 m of the bottom (depth 412–466 m) on 24 July 1973. Our specimen agrees with the type (USNM 64110) and the detailed description of new material by Stein (1978); we add only new meristic data. Counts of our specimen, a female with large eggs, are as follows: D 45; A 41; pect. 33; caudal 7; vert. 49; pyloric caeca 11. Fresh specimen bright pink with transparent skin; iris white, pupil black; lining of mouth reddish. The collection extends the range of this species southward about 1,022 km from the Columbia River mouth, Oregon (Stein 1978).

Elassodiscus caudatus Gilbert, 1915

A single specimen of this little-known snailfish (CAS 29947, 62 mm SL) was collected by otter trawl fished at 212–241 m on 19 December 1973. Smaller than the type, this trawl-damaged specimen at first appeared to represent an undescribed species of *Careproctus,* until details of its rudimentary disk were discovered. Stein (1978) redescribed the species from five new specimens and pointed out its relationship to *Careproctus,* not *Paraliparis,* as originally described. A brief description of the seventh reported specimen follows: D 50; A 41; pect. 27; caudal 9; pyloric caeca 13; vert. 54; GR 0+9; head length 28.1 % SL; snout to vent 15.5 % SL; maxillary length 52.9 % head length (HL); eye 22.4% HL: disk 6.9% HL (methods follow Burke 1930 and Stein 1978). The right side of the specimen was badly damaged in the trawl and the opercular opening on the left side, though observed to be a small slit entirely above the pectoral fin base, was inadvertently ripped on examination. Anteriormost teeth on both jaws long and recurved, becoming short and trilobed posteriorly. Color of fresh specimen pale pinkish-white with scattered melanophores on body and tail; mouth pale; gill cavity black. The stomach contained the remains of two amphipods, *Orchomene obtusa.* The species ranges from Monterey Bay to southeastern Alaska along the upper continental slope (Stein 1978).

Paraliparis albescens Gilbert, 1915

Five of these rare snailfish (Figure 1), known previously only from the holotype taken in Monterey Bay, were captured by us in Monterey Canyon between 192 and 500 m; all were taken by open trawls or traps, so exact capture depths are unknown. Another specimen was taken from the mouth of a bocaccio, *Sebastes paucispinis,* caught by otter trawl fished off Point Conception in 183 m. All six agree with the type, which is in recognizable but brittle condition. We could find no other specimens of this species.

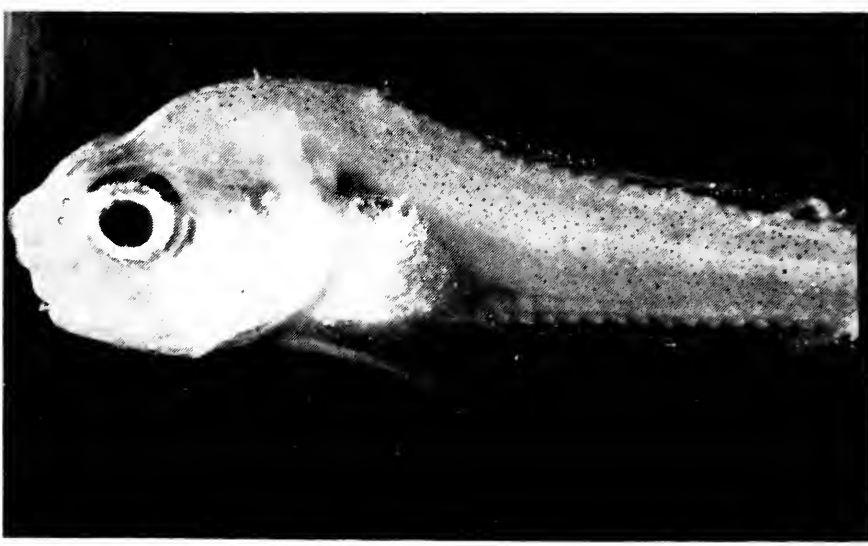

Figure 1. *Paraliparis albescens,* CAS 30466. *Photograph by Gary R. McDonald.*

Literature Records

Paraliparis albescens Gilbert 1915: 355–356, pl. 18, fig. 13, ALBATROSS sta. 4515, lat 36° 46.5′ N, long 121° 56.3′ W, beam trawl in 362–905 m; Jordan, Evermann and Clark 1930: 404; Burke 1930: 193; Schmidt 1950: 213–214; Fitch and Lavenberg 1968: 144; Fitch and Lavenberg 1975: 132; Kukowski 1972: 18, 35.

Material Examined

Holotype, USNM 75816 (57 + mm SL); CAS 29950 (61.0 mm SL); CAS 30466 (58.0 mm SL); CAS 30467 (45.0 mm SL); CAS 35952 (29.0 mm SL); MLML DB-36 (6808), (56.5 mm SL); MLML DB-55 (6808), (53.7 mm SL).

Diagnosis

Mouth horizontal; gill slit above pectoral fin base and extending ventrally in front of 6-12 rays; stomach and peritoneum dusky; teeth in five or six rows anteriorly on jaws, simple, recurved; pectoral fin rays 17-18; head length 20.3-24.4% SL.

Description

Head wide, rounded; snout steep and angular projecting beyond mouth, forming rounded knob above premaxillary symphysis. Eye large, rounded, not entering dorsolateral profile. Mouth moderate with very small, simple, recurved teeth in bands on upper and lower jaws. Upper jaw extending to middle of eye. Gill cover supported by a posteriorly curved spine. Nostril single, without flap. Gill slit extending to opposite 6th to 12th pectoral ray. Pectoral fin of two lobes, the lower composed of four widely exserted rays, the upper rounded, with no exserted rays. Insertion of pectoral nearly on a level with middle of eye. Body elongate, tapering rapidly to fine caudal fin nearly confluent with dorsal and anal fins. Caudal composed of four to six rays. Dorsal and anal fins highest anteriorly, posterior rays half as thick as anterior ones. Skin thin and transparent, torn away in most specimens. Stomach moderately large, thick-walled. Pyloric caeca stout.

Color light pink in life, fading to light tan in alcohol; iris black; stomach, peritoneum and pyloric caeca dusky.

Meristic and morphometric data as follows: D 50-57; A 44-53; pect. 17-18; caudal 4-6; vert. 8-9 + 46-52 = 54-61; pyloric caeca 6-10. Head length 23.1% (20.3-24.4) SL; head width behind orbits 12.3% (8.8-15.8) SL; eye diameter 68.5% (56.0-86.8) maxillary length; head depth behind orbits 15.5% (13.4-18.2) SL; snout length 4.8% (3.7-5.9) SL; maxillary length 9.7% (7.8-11.4) SL; mouth width at rictus 10.3% (9.3-11.7) SL; gill slit length 7.4% (6.2-8.4) SL; snout to anus 21.5% (18.9-22.7) SL; pectoral fin base 11.9% (11.4-12.9) SL; preanal length 35.5% (33.8-38.9) SL; predorsal length 24.0% (22.9-26.2) SL.

Relationships

After an examination of liparid types and new material in several museums, it appears that Gilbert's (1915) decision that *P. albescens* represents a unique form not closely related to other species (in the eastern North Pacific) is warranted. Schmidt (1950) compared his *P. albeolus* from the Sea of Okhotsk with *P. albescens* and, apparently, this western Pacific form is closest to Gilbert's species.

Remarks

To our knowledge, only the holotype and our six specimens are known. All five recent Monterey Bay specimens were females; the smallest at 29.0 mm SL had developing ova; another at 45.0 mm SL had eggs so large that the coelom bulged outward. The Point Conception specimen at 53.7 mm SL is the only known male. Because of the delicate nature of the species and the occurrence of one specimen in a midwater trawl catch, we suggest a benthopelagic existence for *P. albescens.* In support of this, Chlapowski and Krzeptowski (1978) reported pelagic captures of *Paraliparis gracilis* [?] from Poland's Antarctic krill explorations.

Allocyttus folletti Myers, 1960

Two oxeye oreos were collected by Charlie Adams, owner of the commercial trawler TRITON (from Eureka) on 16–17 March 1977. The first (CAS 39087; 234 mm SL) was taken off Cypress Point, Monterey County, lat 36° 33.5′ N, long 122° 01.1′ W in about 550–640 m. The second (CAS 39088; 240 mm SL) was captured off Point Sur, Monterey County, lat 36° 12.0′ N, long 121° 58.0′ W in about 550–600 m. The latter specimen extends the southern range limit by about 417 km (Miller and Lea 1972). Meristic counts for the two specimens are as follows: CAS 39087—D VII, 32; A III, 31; pect. 21/20 (L/R); caudal i, 6, 7, i (principal rays); vert. 39; GR 6 + 20/6 + 21 (L/R); CAS 39088—D VII, 32; A III, 31; pect. 20/20; caudal i, 6, 7, i; vert. 39; GR 6 + 19/6 + 18.

Lycenchelys camchatica (Gilbert and Burke, 1912)

A single specimen of the Kamchatkan eelpout (CAS 31495, 116 mm SL) was captured by a midwater trawl that inadvertently struck bottom in 768–915 m in the axis of Monterey Canyon. It agrees with the type (USNM 74396) and redescription of the species by Andriashev (1937; partim, females only) and Peden (1973). Since the species is not well known, and the few published records suggest it may be more widely distributed in the North Pacific than presently believed, a search for other specimens in U. S. museums was undertaken. The search produced 65 more specimens, usually identified as *Embryx crotalinus.* All captures were made by bottom trawls fished between about 260 and 1,950 m. We add the following counts from 25 specimens to supplement Peden's (1973) redescription of two individuals (methods of counting fin rays follow Peden and Anderson 1978): D112–117; A 100–105; pect. 13–15; caudal 8; vert. 21–23 + 97–103 = 118–124; GR 0–2 + 14–16 = 14–17; vomerine teeth 2–6; palatine teeth 2–7.

Color uniformly purplish-blue posteriorly fading in alcohol to a brownish-pink. Margins of dorsal, anal, and pectoral fins black, throat black. Lining of mouth and gill cavity dark, probably black in life. Nape, cheeks, and snout purple.

Specimens over 140 mm SL appear close to sexual maturity. No specimens from California waters were as large as those from northern waters, probably due to inadequate sampling of the population. The species is presently known from Avacha Bay, USSR to northern Baja California. *L. camchatica* is very similar to *Embryx crotalinus* but is distinguished from the latter by its lower number of pectoral fin rays, gill rakers and vertebrae and the presence of vomerine and palatine teeth. The nominal genus *Embryx* Jordan and Evermann has been retained here pending further systematic study by Anderson.

Material Examined

USNM 149788, Oregon, ALBATROSS sta. 3788, lat 43° 01.0′ N, long 125° 11.0′ W, 1,946 m, 27 Apr. 1901; USNM 135634, Washington, ALBATROSS sta. 2871, lat 46° 55.0′ N, long 125° 11.0′ W, 1,022 m, 23 Sept. 1888; CAS 38304, California, lat 35° 13.4′ N, long 121° 39.5′ W, 1,021 m, 7 Sept. 1976; CAS 31495, California, lat 36° 46.7′ N, 121° 59.5′ W, 768–915 m, 22 Sept. 1974; CAS 39568, Oregon, lat 44° 40.0′ N, long 124° 58.2′ W, 825 m, 22 Oct. 1972; SIO 74-168, California, lat 35° 29.3′ N, long 121° 35.7′ W, 905 m, 1 Apr. 1974; SIO 71-90, Baja California, lat 32° 25.3′ N, long 117° 28.9′ W, ca. 1,244 m, May 1971; SIO 71-162, California, lat 32° 53.0′ N, long 117° 31.8′ W, ca 790 m, 13 Aug. 1971; SIO 72-55, Baja California, lat 32° 25.8′ N, long 117° 28.8′ W, 1,225–1,244 m, 14 Sept. 1971; SIO 74-197, California, lat 32° 43.5′ N, long 119° 28.9′ W, 1,363 m, 5 Sept. 1974; SIO 74-198, California, lat 32° 50.2′ N, long 119° 31.7′ W, ca. 1,100 m, 5 Sept. 1974.

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REFERENCES

Anderson, M. E. 1977. Systematics and natural history of the midwater fish *Lycodapus mandibularis* Gilbert in California waters. M. A. Thesis. California State University, Hayward, 89 pp.

Anderson, M. E., and G. M. Cailliet. 1975. Occurrence of the rare North Pacific frostfish, *Benthodesmus elongatus pacificus* Parin and Becker, 1970, in Monterey Bay, California. Calif. Fish Game 61(3): 149-152.

Andriashev, A. P. 1937. Contributions to the knowledge of the fishes from the Bering and Chukchi seas. Leningrad Inst. Hydro., Expl. mers de l'URSS Fasc. 25: 292-355.

Aughtry, R. H. 1953. A note on mass mortality of the myctophid fish *Tarletonbeania crenularis*. Copeia 1953 (3): 190-192.

Bolin, R. L. 1937. Notes on California fishes. Copeia 1937 (1): 63-64.

______ 1940. Brown ragfish taken at Monterey. Calif. Fish Game 26 (3): 287-289.

Burke, V. 1930. Revision of the fishes of the family Liparidae. U. S. Natl. Mus., Bull. (150): 204 pp.

Cailliet, G. M., and M. E. Anderson. 1975. Occurrence of the prowfish *Zaprora silenus* Jordan, 1896 in Monterey Bay, California. Calif. Fish Game 61(1): 60-62.

Cailliet, G. M., B. Antrim, D. Ambrose, S. Pace, and M. Stevenson. 1977. Species composition, abundance and ecological studies of fishes, larval fishes and zooplankton in Elkhorn Slough. Pages 216–386 *in* J. Nybakken, G. Cailliet and W. Broenkow, eds. Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing Harbor and nearshore coastal waters, July 1974 to June 1976. Moss Landing Mar. Lab.

Cailliet, G. M., and R. N. Lea. 1977. Abundance of the "rare" zoarcid *Maynea californica* Gilbert, 1915, in the Monterey Canyon, Monterey Bay, California. Calif. Fish Game 63(4): 260–268.

Chlapowski, K., and M. Krzeptowski. 1978. On the presence of fishes in Antarctic krill catches. Acta Ich. Pisc. 8(1): 1-8.

Fast, T. N. 1957. The occurrence of the deep-sea anglerfish *Cryptosaras couesii,* in Monterey Bay, California. Copeia 1957 (3): 237-240.

Fitch, J. E., and R. J. Lavenberg. 1968. Deep-water teleostean fishes of California. Univ. Calif. Press 155 pp.

______ 1975. Tidepool and nearshore fishes of California. Univ. Calif. Press. 156 pp.

Follett, W. I. 1970. Benthic fishes cast ashore by giant waves near Point Joe, Monterey County, California. Calif. Acad. Sci., Proc. Fourth ser. 37(15): 473-488.

Gilbert, C. H. 1899. Report on fishes obtained by the steamer "Albatross" in the vicinity of Santa Catalina Island and Monterey Bay. U.S. Comm. Fish., Rept. Part 24: 25–29.

______ 1915. Fishes collected by the United States fisheries steamer "Albatross" in southern California in 1904. U.S. Natl. Mus., Proc. 48: 305–380.

Gregory, P. 1969. The addition of the mirror dory, *Zenopsis nebulosa* (Temminck and Schlegel), to the California fauna. Calif. Fish Game 55(3): 243–245.

Jordan, D. S., B. W. Evermann, and H. W. Clark. 1930. A checklist of the fishes and fishlike vertebrates of North and Middle America north of Venezuela and Columbia. U.S. Comm. Fish., Rept. Part II, Bur. Fish., U.S. Dept. Commer.: 670 pp.

Kliever, R. G. 1976. Natural history of *Maynea californica* (Pisces: Zoarcidae) in a drift seaweed habitat in the Monterey Submarine Canyon, Monterey Bay, California. M. A. Thesis. California State University, San Jose. 70 pp.

Kukowski, G. E. 1972. A checklist of the fishes of the Monterey Bay area including Elkhorn Slough, the San Lorenzo, Pajaro and Salinas Rivers. Moss Landing Mar. Lab. Tech. Publ. (72-2). 69 pp.

McCosker, J. E., and M. E. Anderson. 1976. Aquarium maintenance of mesopelagic animals: a progress report. South. Calif. Acad. Sci., Bull. 75(2): 211–219.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Dept. Fish Game, Fish Bull. (157). 235 pp.

Osada, E. K., and G. M. Cailliet. 1975. Trap-caught sablefish in Monterey Bay. Am. Fish. Soc., Cal-Neva Wildlife Trans.: 56–73.

Peden, A. E., 1973. Records of eelpouts of the genus *Lycenchelys* and *Embryx* from the northeastern Pacific Ocean. Syesis 6: 115–120.

Peden, A. E., and M. E. Anderson. 1978. A systematic review of the fish genus *Lycodapus* (Zoarcidae) with descriptions of two new species. Can. J. Zool. 56(9): 1925–1961.

Phillips, J. B. 1932. Ribbon-fish taken at Monterey. Calif. Fish Game 18(1): 99–100.

______ 1952. Yellow sablefish (black cod) taken in Monterey Bay. Calif. Fish Game 38(3): 437–438.

______ 1961*a*. Range extensions for two California fishes with a note on a rare fish. Calif. Fish Game 47(4): 418.

______ 1961*b*. Two unusual cephalopods taken near Monterey Bay. Calif. Fish Game 47 (4): 416–417.

______ 1967. A longfin sanddab, *Citharichthys xanthostigma,* and a skilfish, *Erilepis zonifer,* taken in Monterey Bay. Calif. Fish Game 53(4): 297–298.

Schmidt, P. Yu. 1950. Fishes of the Sea of Okhotsk. (Transl. from Russian). Isr. Program Sci. Transl. Ltd. TT 65-50022. 392 pp.

Sette, O. E. 1923. The occurrence of *Trachypterus rex-salmonorum* at Monterey and notes on its post-larval growth. Copeia 1923 (1): 93–96.

Stein, D. L. 1978. A review of the deepwater Liparidae (Pisces) from the coast of Oregon and adjacent waters. Calif. Acad. Sci. Occas. Papers (127): 55 pp.

Taylor, L. 1972. *Apristurus kampae,* a new species of scyliorhinid shark from the eastern Pacific Ocean. Copeia 1972 (1): 71–77.

Thompson, W. F. 1920. Occurrence of a deep-sea fish at Monterey. Calif. Fish Game 6(2): 83.

______ 1921. A rag fish at Monterey. Calif. Fish Game 7(3): 179.

Calif. Fish and Game 65(4): 265–272 79

AGE AND GROWTH OF FOUR SURFPERCHES (EMBIOTOCIDAE) FROM THE OUTER HARBOR OF ANAHEIM BAY, CALIFORNIA [1]

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Age and growth data were collected and analyzed for four species of surfperches, *Cymatogaster aggregata, Embiotoca jacksoni, Hyperprosopon argenteum,* and *Phanerodon furcatus.* Standard length to total length, scale radius to standard length, and otolith radius to standard length relationships were constant for all four species, thus allowing for back calculating the ages. Slopes of the length-weight relationship for the four species were all approximately 3.0, indicating isometric growth.

INTRODUCTION

Of the 19 species of marine embiotocids known to occur along the California coast (Miller and Lea 1972), studies of age and growth have been reported for only nine. Studies have been conducted on size at age and/or growth rates of the reef surfperch, *Micrometrus aurora,* (Hubbs 1921); kelp surfperch, *Brachyistius frenatus,* (Hubbs and Hubbs 1954); shiner surfperch, *Cymatogaster aggregata,* (Suomela 1931; Gordon 1965; Anderson and Bryan 1970; Odenweller 1971); striped surfperch, *Embiotoca lateralis,* (Sivalingam 1956; Swedberg 1965); black surfperch, *Embiotoca jacksoni,* (Isaacson and Isaacson 1966); white surfperch, *Phanerodon furcatus,* (Anderson and Bryan 1970; Banerjee 1973); and walleye surfperch, *Hyperprosopon argenteum,* (Anderson and Bryan 1970). Aspects of the life history of the barred surfperch, *Amphistichus argenteus,* were studied by Carlisle, Schott, and Abramson (1960). Reports were made on the biology of the striped surfperch (Gnose 1967), and the pile perch, *Damalichthys vacca* (Wares 1971). The family Embiotocidae was revised by Tarp (1952).

In this study, age and growth rates were determined for the shiner surfperch, black surfperch, walleye surfperch, and white surfperch.

MATERIALS AND METHODS

From June 1972 to June 1973, 1,461 surfperches were collected in the outer harbor of Anaheim Bay, Orange County, California. Collections were made at least once a month. Two sizes of seines were used, a 15.2 $\times$ 1.8-m bag seine with 3.2-mm bar mesh and a 30.4 $\times$ 1.8-m seine with 18.1-mm bar mesh. I also used a shrimp otter trawl which measured 4.9-m in width at the mouth; the throat was made of 1.85-cm bar mesh nylon netting, and the cod end was made from 1.3-cm bar mesh nylon netting with a liner of 0.6-cm woven nylon netting.

The fishes were preserved in 10% formalin and fresh water for 24 hr and transferred to 40% isopropyl alcohol before being weighed and measured, after at least 24 hr.

Sex was determined by external dimorphic characters. Males of the family

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exhibit a bulbous anal fin "organ" described by Eigenmann (1892), Tarp (1952), and Carlisle et al. (1960).

Surfperches were weighed to the nearest 0.01 g, and both standard length (SL) and total length (TL) were measured to the nearest millimeter.

Scales were taken from the area beneath the left pectoral fin and otoliths were removed. Scales were mounted in a trypsin solution between glass slides, and their images projected onto a white screen; the distance between annuli was measured with a ruler. Otoliths were placed in a black bottom dish (Schott 1965) filled with oil of anise and read through a dissecting microscope with reflected light; the distance between annuli was measured with an optical micrometer.

Calculations on growth data for all species included the length-weight relationship, standard length to total length relationship, and back-calculated lengths. The von Bertalanffy (1938) growth equations were calculated by the methods given in Gulland (1965) and instantaneous growth rates were estimated as given in Ricker (1975).

RESULTS AND DISCUSSION

Length-weight relationships for each species by sex (Table 1) were all found to have the expected high correlation coefficient for the linear log length to log weight relations. Black surfperch were heaviest for any given length.

The differences in length-weight relations were more apparent between the sexes than among the species. Male shiner surfperch less than 90 mm SL were heavier than females; however, at 90 mm and above, females were heavier. This relationship was found also in white surfperch at 100 mm SL, and in black surfperch at 140 mm SL. Walleye surfperch exhibited the opposite relationship; males were heavier at 130 mm and above. Carlisle et al. (1960) also observed differences in the rate of increase in weight for male and female surfperches.

The ratio of total length to standard length remained constant in all four surfperches (Table 2). This relationship differs from that observed by Anderson and Bryan (1970). Their ratio for shiner surfperch, walleye surfperch, and white surfperch decreased with increasing size. The difference might be attributed to the different collection sites or to environmental conditions (Carlander and Smith 1945).

Walleye surfperch and white surfperch were most easily aged by scales, black surfperch by otoliths, and shiner surfperch by the Peterson length frequency distribution. Three types of checks were found on surfperch scales: birth check, spawning checks, and annuli. Distinguishing characteristics of scales are described by Anderson and Bryan (1970). Otoliths consisted of an opaque nucleus followed by alternating translucent and opaque bands.

The SL to scale radius (SR) relationship for walleye surfperch between 51 and 164 mm was $y = 0.687X + 39.642$, with $r = 0.864$, where $y = SL$, $X = SR(35)$ in millimeters, and r = correlation coefficient. For white surfperch between 54 and 200 mm, $y = 0.677X + 26.646$, with $r = 0.900$.

The SL to otolith radius (OR) relationship for black surfperch between 73 and 215 mm was $y = 51.717X - 19.067$ with $r = 0.923$, where $Y = SL$, $X = OR(7)$ in millimeters, and r = correlation coefficient.

Back-calculated lengths were determined for black surfperch, walleye surfperch, and white surfperch (Table 3). These species had similar growth histories with the amount of growth decreasing with age (Table 4).

TABLE 1. Length-weight Relationships ($W = aL^b$) for Anaheim Bay Surfperches from June 1972 to June 1973, with Length being Standard Length in Millimeters. Sample Sizes (n) and Correlation Coefficients (r) are in Parenthesis. 95% Confidences Intervals are Listed for "b"

Species	*Female*		*Male*	
	Length-weight relationship	*95% Confidence interval of "b"*	*Length-weight relationship*	*95% Confidence interval of "b"*
Cymatogaster aggregata	$W = 9.697 \times 10^{-6} L^{3.212}$ (n=122; r=0.978)	3.161 to 3.263	$W = 1.580 \times 10^{-5} L^{3.111}$ (n=77; r=0.999)	2.965 to 3.257
Embiotoca jacksoni	$W = 1.472 \times 10^{-5} L^{3.200}$ (n=121; r=0.988	3.110 to 3.290	$W = 3.122 \times 10^{-5} L^{3.044}$ (n=113; r=0.986)	2.947 to 3.141
Hyperprosopon argenteum	$W = 1.714 \times 10^{-5} L^{3.114}$ (n=333; r=0.988)	2.962 to 3.064	$W = 9.448 \times 10^{-5} L^{3.238}$ (n=213; r=0.946)	2.832 to 3.124
Phanerodon furcatus	$W = 2.254 \times 10^{-5} L^{3.013}$ (n–178; r=0.965)	2.893 to 3.133	$W = 2.655 \times 10^{-5} L^{2.978}$ (n=118; r=0.966)	2.842 to 3.114

TABLE 2. Standard Length to Total Length Relationships for Anaheim Bay Surfperches in Millimeters. In Parenthesis are the Sample Sizes (n) and Correlation Coefficients (r)

Cymatogaster aggregata	TL=1.245 SL + 1.771 (n=238; r=0.982)
Embiotoca jacksoni	TL=1.238 SL + 2.911 (n=275; r=0.994)
Hyperprosopon argenteum	TL=1.228 SL + 4.320 (n=611; r=0.992)
Phanerodon furcatus	TL=1.296 SL + 1.584 (n=377; r=0.992)

TABLE 3. Comparison of Length Derived from the von Bertalanffy Growth Equation to that Derived by Back Calculating

Embiotoca jacksoni

End of year	*Standard length at age (mm)*	
	von Bertalanffy	*Back calculating*
1	109.3	109.5
2	146.6	146.1
3	171.9	173.0
4	189.0	188.9

Hyperprosopon argenteum

End of year	*Standard length at age (mm)*	
	von Bertalanffy	*Back calculating*
1	85.4	86.4
2	122.1	123.9
3	143.6	140.2
4	156.1	157.1

Phanerodon furcatus

End of year	*Standard length at age (mm)*	
	von Bertalanffy	*Back calculating*
1	107.3	107.8
2	140.0	140.9
3	161.5	161.2
4	175.5	174.2
5	184.7	185.2
6	190.6	197.3
7	194.6	193.0

Male and female black surfperch and walleye surfperch appeared to have similar life spans, while female white surfperch seemed to live longer than males.

Shiner surfperch appeared to be short-lived; the oldest specimen collected was a 2-year old female, 112 mm SL. One-year old specimens had a mean standard length of 68.4 mm, while that of 2-year olds was 100.3 mm. There were no apparent age-length differences between the sexes.

The age-length relationship for all four surfperches was found to fit the von Bertalanffy growth equation. The fitted constants for the von Bertalanffy growth equation (Table 5) yielded lengths at age similar to those found by back-calculating (Table 3).

TABLE 4. Back-calculated Lengths in Millimeters at Age

Embiotoca jacksoni

	Number		Mean standard length at end of year							
			I		*II*		*III*		*IV*	
Age class	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
I	37	35	109.9	109.0						
II	21	13	110.2	104.8	147.2	144.4				
III	6	9	114.5	115.9	149.0	155.6	169.0	176.4		
IV	3	2	122.0	112.2	160.5	142.4	178.4	171.4	189.8	187.6
Weighted mean standard length			111.0	109.2	148.9	148.4	171.5	175.5	189.8	187.6
Growth increment			61.0	58.2	37.9	39.2	22.6	27.1	18.3	12.1

Hyperprosopon argenteum

	Number		Mean standard length at end of year							
			I		*II*		*III*		*IV*	
Age class	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
I	103	108	86.5	86.3						
II	48	98	90.4	86.8	123.1	124.3				
III	3	27	91.3	88.5	124.4	123.9	138.0	140.4		
IV	–	5	–	85.7	–	121.7	–	140.1	–	157.1
Weighted mean standard length			87.7	86.7	123.2	124.1	138.0	140.4	–	157.1
Growth increment			25.3	24.9	35.4	37.4	14.8	16.3	–	16.7

TABLE 4. (Continued)

Phanerodon furcatus

Age group	Number		Mean standard length at end of year														
			I		*II*		*III*		*IV*		*V*		*VI*		*VII*	
	M	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*	*M*	*F*
I	26	27	109.0	106.6												
II	50	66	103.8	105.0	140.8	141.0										
III	22	32	107.2	103.9	138.4	139.7	161.0	161.4								
IV	3	27	107.0	102.0	137.7	141.8	161.1	161.1	173.0	174.3						
V	–	5	–	102.4	–	142.9	–	163.6	–	176.3	–	185.2				
VI	–	1	–	103.0	–	130.1	–	162.3	–	172.8	–	184.2	–	197.3		
VII	–	1	–	104.7	–	143.7	–	165.1	–	175.8	–	183.4	–	189.5	–	193.0
Weighted mean standard length			106.0	104.5	140.0	140.9	161.0	161.5	173.0	174.6	–	184.8	–	193.4	–	193.0
Growth increment			106.0	104.5	34.0	36.4	21.0	20.6	12.0	13.1	–	10.2	–	8.6	–	(−0.4)

TABLE 5. Constants and Standard Errors for von Bertalanffy Growth Equation, $l_t = L_\infty (1-e^{-k(t-t_0)})$, from Four Surfperches from Anaheim Bay, California

Species	L_∞ Estimate	L_∞ Standard error	k Estimate	k Standard error	t_o Estimate	t_o Standard error
Cymatogaster aggregata	128.7	0.285	0.063	0.003	−0.45 (months)	0.023
Embiotoca jacksoni	224.95	0.093	0.390	0.001	−0.705 (years)	0.008
Hyperprosopon argenteum	173.67	0.031	0.538	0.001	−0.257 (years)	0.011
Phanerodon furcatus	201.95	0.056	0.425	0.001	−0.782 (years)	0.003

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REFERENCES

Anderson, R. D., and C. F. Bryan. 1970. Age and growth of three surfperches (Embiotocidae) from Humboldt Bay, California. Amer. Fish. Soc., Trans., 99(3):475–482.

Banerjee, T. 1973. Age and growth of the white seaperch (*Phanerodon furcatus*) from Tomales Bay, California. Amer. Fish. Soc., Trans., 102(2):448–450.

Carlander, K. D., and L. L. Smith, Jr. 1945. Some factors to consider in the choice between standard, fork, and total lengths in fishery investigations. Copeia 1945 (1):7–12.

Carlisle, J. G., Jr., J. W. Schott, and N. J. Abramson. 1960. The bared surfperch (*Amphistichus argenteus*) in southern California. Calif. Dept. Fish and Game, Fish Bull. (109):1–70.

Eigenmann, C. H. 1892. On the viviparous fishes of the Pacific coast of North America. U. S. Fish. Comm., Bull., 12:381–382 and 401–478.

Gordon, D. C. 1965. Aspects of the age and growth of *Cymatogaster aggregata* Gibbons. M. S. Thesis Univ. of British Columbia, Vancouver. 90 p.

Gnose, C. E. 1967. The ecology of the striped surfperch, *Embiotoca lateralis,* in Yaquina Bay, Oregon. M.S. Thesis. Oregon State Univ. 51 p.

Gulland, J. A. 1965. Manual of methods for fish stock assessment. Pt. 1. Fish population analysis. FAO Fish. Tech. Pap. Rev., 1 (40):1–70.

Hubbs, C. L. 1921. The ecology and life history of *Amphigonopterus aurora* and other viviparous perches of California. Biol. Bull., 40(4): 181–209.

Hubbs, C. L., and L. C. Hubbs. 1954. Data on the life history, variation, ecology and relationships of the kelp perch, *Brachyistius frenatus*, an embiotocid fish of California. Calif. Fish Game, 40(2):183–198.

Isaacson, P. A., and D. M. Isaacson. 1966. Notes on the life history of the black perch, *Embiotoca jacksoni* Agassiz. Amer. Fish. Soc., Trans., 95(1): 107–109.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish and Game, Fish. Bull. (157):1–235.

Odenweller, D. B. 1971. The life history of the shiner perch, *Cymatogaster aggregata* Gibbons, in Anaheim Bay. M.A. Thesis Calif. State College, Long Beach. 66 p.

Ricker, W. E. 1975. Computations and interpretation of biological statistics of fish populations. Canada, Fish. Res. Bd., Bull. (191):1–382.

Schott, J. W. 1965. A visual aid for age determination of immersed otoliths. Calif. Fish Game, 51(1):56.

Sivalingam, S. 1956. Age and growth of *Taeniotoca lateralis*. Ceylon J. Sci., Sec. C. Fish 1 (new series):135–181.

Suomela, A. J. 1931. The age and growth of *Cymatogaster aggregata* Gibbons collected in Puget Sound, Washington. M. S. Thesis, Univ. of Washington, Seattle, Wash., 43 p.

Swedberg, S. E. 1965. Age-fecundity relations in the striped seaperch *Embiotoca lateralis*, from Yaquina Bay, Oregon. M. S. Thesis, Oregon State Univ., Corvallis, Ore., 39 p.

Tarp, H. F. 1952. A revision of the family Embiotocidae. Calif. Dept. Fish and Game, Fish Bull. (88):1–99.

von Bertalanffy, L. 1938. A quantitative theory of organic growth. Human Biol., 10:181–243.

Wares, P. G. 1971. Biology of the pile perch, *Rhacochilus vacca*, in Yaquina Bay, Oregon. U. S. Dept. Interior, Bur. Sportfish Wildlife, Tech. Papers, (57):1–21.

FISH REMAINS FROM A HISTORIC CENTRAL CALIFORNIA INDIAN VILLAGE

INTRODUCTION

The fauna of California has undergone marked changes in the last 125 years, and this is especially true of the fishes of the Sacramento-San Joaquin Valley. Many of the native fish species have become severely depleted, and a few have been brought to the verge of extinction. Little quantitative information is available from which to judge either the early abundance of these depleted forms or the rapidity of their decline. Since archaeology can provide one source of such information, fish remains from a historic Indian midden in the Sacramento Valley were investigated.

SITE

The Patwin village of Tsaki (archaeological site CA-Col-1) was a large settlement located about 0.5 km west of the Sacramento River, in southern Colusa County, California. The site was established prior to 800 A.D. and abandoned about 1870. In historic times Tsaki served as the main village of a small independent tribelet. The subsistence economy of its people depended on gathering wild plants, fishing, and hunting. Salmon are reported to have been the most important fish species in the native diet, and Tsaki cooperated with several other Patwin tribelets in operating a salmon weir near the modern town of Grimes (Kroeber 1932). An additional fishery for freshwater species was carried on by family groups of specialists who controlled fishing rights in neighboring lakes and sloughs (McKern 1922).

METHODS

Archaeological investigations of the upper (historic) portion of the site were conducted by the University of California, Davis, in 1973. Four 150-by-150 cm excavation units were selected at random for examination of fish remains. Depth and provenience were maintained by arbitrary 10-cm levels. Total volume of the utilized units was 14.6 m^3, representing less than 1% of the total deposit.

All earth from the units was passed through ⅛-inch mesh screens. The recovered material was washed and returned to the laboratory, where it was sorted under a 3× illuminated magnifier. Fish remains were extracted and identified to species whenever possible. The minimum number of individuals present was established by counting the most abundant element (index element) for each species.

RESULTS

Remains of eleven species of fishes totaling a minimum of 1,497 individuals were recovered (Table 1). The most abundant fish in the midden (41%) was the thicktail chub, *Gila crassicauda*. Less abundant, but also common, were Sacramento perch, *Archoplites interruptus*; hitch, *Lavinia exilicauda*; Sacramento blackfish, *Orthodon microlepidotus*; and splittail, *Pogonichthys macrolepidotus*. The remaining six species constituted less than 3% of the fauna. Some variation in relative abundance of species was present from level to level, but no trends were discernible through time and the fluctuations apparently result from differences in individual catches.

DISCUSSION

The most striking feature of the Tsaki fauna is the predominance of thicktail chub—a minnow which is probably now extinct. The abundance of Sacramento perch is also noteworthy, since it too has been virtually eliminated, by habitat modification and the introduction of competing species, from open water habitats in the Sacramento Valley. The paucity of salmon and sturgeon remains in the midden is in accord with Kroeber's (1932) statement that these fish were generally filleted at the weir, leaving few bones to be returned to the site.

The aquatic habitat from which the Tsaki fish were derived is readily determined, since the four most abundant species (93% of the fauna) are primarily inhabitants of lentic environments. The remains of these fishes clearly come from the Patwin lake-slough fishery, although seasonally flooded lands may have been as important in providing fish as permanent lakes and sloughs. Splittail, normally found in the main channel of the Sacramento, are known to spawn in the spring over flooded grasslands (Caywood 1974) and this may have been an important element in the life cycle of thicktail chubs and Sacramento perch as well (Dibble, Buckingham, and Redding 1884; Miller 1963).

Although the thicktail chub was noted as the third most abundant species in a prehistoric Indian midden in the lower Sacramento Valley (Schulz and Simons 1973), its status in early historic times has been uncertain. Lockington (1879) rated its occurrence in the San Francisco fish market as only "occasional", and most nineteenth century numerical summaries of commercial freshwater fish landings ignore it entirely or combine it with other cyprinids under imprecise common names. Only Collins (1892) has reported it as abundant (during 1888) in the Sacramento River. There is no question, however, about its present rarity; in spite of extensive surveys only two specimens have been taken since 1938, the last in 1957 (Miller 1963; S. Nicola, Senior Fishery Biologist, Department of Fish and Game, pers. commun.).

It is now evident that this species survived in considerable numbers into historic times, and that it was a major element in the native fishery of the Sacramento Valley. The present data further suggest that the decline did not begin until after the abandonment of Tsaki quite late in the nineteenth century.

ACKNOWLEDGMENTS

I wish to thank Margaret Miller, Martha Miller, and Mr. and Mrs. Harold Kuppenbender for permission to work at the site. I am grateful to M.C. Essig for laboratory assistance and to W.I. Follett, P.B. Moyle, and S.J. Nicola for helpful criticisms of the report.

Table 1. Frequency of Occurrence of Fish Species at Tsaki

Species	*Common name*	*Index element*	*Individuals*	*%*
Gila crassicauda	Thicktail chub	Right pharyngeal	620	41.4
Archoplites interruptus	Sacramento perch	First vertebra	368	24.6
Lavinia exilicauda	Hitch	Right pharyngeal	276	18.4
Orthodon microlepidotus	Sacramento blackfish	Right pharyngeal	131	8.8
Pogonichthys macrolepidotus	Splittail	Left pharyngeal	59	3.9
Ptychocheilus grandis	Sacramento squawfish	Right pharyngeal	13	0.9
Catostomus occidentalis	Sacramento sucker	Right pharyngeal	11	0.7
Hysterocarpus traskii	Tule perch	Lower pharyngeal	9	0.6
Oncorhynchus tshawytscha	Chinook salmon	Vertebrae	4	0.3
Mylopharodon conocephalus	Hardhead	Right pharyngeal	4	0.3
Acipenser sp.	Sturgeon	Right hyomandibular	2	0.1
TOTAL			1,497	100.0

REFERENCES

Caywood, M.L. 1974. Contributions to the life history of the splittail, *Pogonichthys macrolepidotus* (Ayres). MS thesis, California State University, Sacramento.

Collins, J.W. 1892. Report on the Fisheries of the Pacific Coast of the United States. U.S. Commiss. Fish Fisher. Rep. 1888:3–269.

Dibble, A.B., R.H. Buckingham, and J.D. Redding 1884. Report. Rep. Commiss. Fisher. St. Calif. 1883–1884:1–33.

Kroeber, A.L. 1932. The Patwin and their neighbors. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 29(4):253–428.

Lockington, W.N. 1879. Report on the food fishes of San Francisco. Rep. Commiss. Fisher. St. Calif. 1878–1879:17–58.

McKern, W.C. 1922. Functional families of the Patwin. Univ. Calif. Publ. Amer. Archaeol. Ethnol. 13(7):235–258.

Miller, R.R. 1963. Synonomy, characters, and variations of *Gila crassicauda*, a rare Californian minnow, with an account of its hybridization with *Lavinia exilicauda*. Calif. Fish Game 49(1):20–29.

Schulz, P.D., and D.D. Simons 1973. Fish species diversity in a prehistoric central California Indian midden. Calif. Fish Game 59(2):107–113.

—Peter D. Schulz, Division of Resource Preservation and Interpretation, California Department of Parks and Recreation, P.O. Box 2390, Sacramento, California 95811. *Accepted for publication May 1979.*

A NORTHERN RANGE EXTENSION FOR THE PORTUNID CRAB, *EUPHYLAX DOVI* (DECAPODA, BRACHYURA)

The northern range of the Portunid crab *Euphylax dovi* was extended recently from Manzanillo, Mexico to Santa Monica Bay, California, an extension of almost 2,220 km (Word 1976). Prior to, and independent of, the aforementioned report, three specimens of *E. dovi* from California waters were found in the collection of the California Academy of Sciences' Department on Invertebrate Zoology (C.A.S.). A manuscript was submitted to *California Fish and Game* only a matter of weeks prior to publication of Word's note.

Because C.A.S. material constitutes earlier California records and a range extension to Monterey Bay, it is herein reported.

In 1959, the California Academy of Sciences acquired, by donation, a large shell and marine "curio" collection from the late Andrew Sorensen of Pacific Grove, California. In addition to molluscan material, there was a dry crustacean collection which contained a single, well preserved specimen of a large male portunid crab (Figure 1), measuring 9.5 cm in maximum carapace width, with the following label: "*Euphylax dovii*—Stimpson, Mission Beach—San Diego—Miss Wilson." The species' identification was valid and established a northern range extension, at that time, of more than 2,200 km. Due to the unscientific nature of the Sorensen collection and the meager information on the original label, publication of a range extension was unwarranted.

Additional specimens of *E. dovi* were found in a large and well documented collection turned over to the Academy by Stanford University's Hopkins Marine Station. Two adult male crabs (Figure 2), measuring 9.2 and 9.5 cm in maximum carapace width, were in a single container with two labels. One label read "*Euphylax dovi* Stimpson. Caught while swimming under Fisherman's Wharf Monterey, California Dec. 6, 1943. R. Campisi Coll., R. L. Bolin Det. Donated by American Fish Co," and the other, "*Euphylax dovi* Stimpson, Monterey Bay, California about 36°50'N. lat., 122°05'W. long. Taken in sardine net Dec. 18, 1943. Chris Avcoleo Coll. R. L. Bolin Det. This label refers to the specimen intact."

Figure 1. Male *Euphylax dovi* from Mission Beach, San Diego, California. *Photograph by Lloyd Ullberg.*

Figure 2. Male *Euphylax dovi* (above) taken in a sardine net in Monterey Bay, California on 18 December 1943. Male *E. dovi* (below) captured under Fisherman's Wharf, Monterey, California on 6 December 1943. Photograph by *Lloyd Ullberg*.

The Hopkins Marine Station specimens, preserved in 75% ETOH, are a maculated reddish-brown with lighter yellowish appendages. The Mission Beach specimen is rose-pink with cream shadings and with gray to black maculations in the epibranchial and hepatic region. All three crabs possess an opalaceous sheen. These colors are, in part, artifacts of the denaturization of carotenoproteins. Life colors are red-purple and blue (Nichols and Murphy 1944; Garth 1948), and they suggest, together with the flattened dactyli and propodi on all four legs, a pelagic existence for at least part of the species' life.

Cyclic warm water periods, resulting in an intrusion of tropical fauna into California waters, have been documented by Hubbs (1948). They are associated with shoreward movement of the Davidson current and periods of little or no upwelling. Reportedly, these phenomena occur from December through February, and have been postulated as the cause of sporadic beaching of pelagic invertebrates such as the pelagic red crab, *Pleuroucodes planipes*, as far north as Monterey Bay (Glynn 1961).

The Mission Beach and Monterey Bay specimens, as well as those reported by Word (1976), establish *E. dovi* as a transient member of the California Brachyuran fauna.

ACKNOWLEDGMENTS

I would like to thank Lloyd Ullberg, California Academy of Sciences' staff photographer for the superb photographs and to John Garth of the Allan Hancock Foundation for assistance given.

REFERENCES

Garth, J. S. 1948. The Brachyura of the "Askoy" Expedition with remarks on carcinological collecting in the Panama Bight. Amer. Mus. Nat. Hist. Bull., 92(1): 1–66.

Glynn, P. W. 1961. The first recorded mass stranding of pelagic red crabs, *Pleuroncodes planipes*, at Monterey Bay, California, since 1859, with notes on their biology. Calif. Fish Game, 47(1): 97–101.

Hubbs, C. H. 1948. Changes in the fish fauna of western North America correlated with changes in ocean temperature. Mar. Res., 7(3): 459–482.

Nichols, J. T. and R. C. Murphy. 1944. A collection of fishes from the Panama Bight, Pacific Ocean. Amer. Mus. Nat. Hist., Bull., 83(1): 217–260.

Word, J. Q. 1976. A swimming crab, *Euphylax dovii* Stimpson 1860, new to the marine fauna of California. Calif. Fish Game, 62(2): 161–162.

—*Dustin D. Chivers, Department of Invertebrate Zoology, California Academy of Sciences, Golden Gate Park, San Francisco, California 94100.* *Accepted for publication March 1979.*

THE INTRODUCTION OF SOUTHEASTERN BLUEGILL, *LEPOMIS MACROCHIRUS PURPURESCENS*, INTO LAKE PERRIS, CALIFORNIA, WITH NOTES ON THE GROWTH OF THE INITIAL YEAR CLASS

The common bluegill, *Lepomis macrochirus macrochirus*, which is widespread in California, has exhibited a tendency toward slow growth or small size in some California impoundments (Bell 1959; Beland 1960; Fast 1966). This characteristic has resulted in the underutilization of many bluegill populations by California anglers. The southeastern bluegill, *Lepomis macrochirus purpurescens*, is a genetically distinct subspecies of the common bluegill (Avise and Smith 1974), characterized by longer fins, higher meristic counts, and different coloration (Hubbs and Allen 1943; Martin 1963). It is reported to exhibit faster growth, larger size, and superior overall sporting qualities than the common bluegill. Federal and State fish hatcheries in Texas and North Carolina have cultured and stocked southeastern bluegill in preference to the common form for many years (King 1947; Miller and Winn 1951).

In 1975 the California Fish and Game Commission approved the experimental introduction of southeastern bluegill in the State. One hundred adult bluegill, supplied by the Florida Game and Fish Commission, were flown by commercial air freight from Florida to Los Angeles on 4 June 1975. Examination revealed no serious parasite or disease organisms and, following removal of the left pelvic fin for later identification, 88 fish were released into Lake Perris, Riverside County, the following day.

Impounded in 1973, Lake Perris has a surface area of 938 ha and 16.1 m of shoreline. As is characteristic of many newly impounded waters, this reservoir is highly fertile and fish growth has been exceptional (Brown, Aasen, and von Geldern 1977). Lake Perris was selected as the initial introduction site because common bluegill were absent. In addition to the southeastern bluegill, Lake

Perris currently sustains populations of Alabama spotted bass, *Micropterus punctulatus*; channel catfish, *Ictalurus punctatus*; green sunfish, *Lepomis cyanellus*; and threadfin shad, *Dorosoma petenense*. Brown trout, *Salmo trutta*, and rainbow trout, *Salmo gairdneri*, are also stocked on a regular basis.

Gill net, creel, and electrofishing surveys were employed to follow the establishment of a reproducing population of southeastern bluegill in Lake Perris. Boat electrofishing surveys were conducted along randomly selected shoreline areas twice monthly from June 1975 until June 1977.

Age and growth determinations were made from fish caught by anglers in the spring of 1977. Fish were measured to the nearest millimeter fork length (FL) and weighed to the nearest gram. Scales were removed from an area immediately posterior to the left pectoral fin for later analysis.

Progeny of the 1975 introduction initially appeared in electrofishing collections in July 1976. At that time four bluegill, ranging in size from 108–125 mm FL, were collected. However, netting surveys failed to capture bluegill progeny until February 1977, when two specimens were collected. Low bluegill density in the reservoir and the selectivity of gill nets against small fish are two factors responsible for the delayed detection of bluegill progeny by netting surveys. Initial meristic analysis of these specimens agreed with reported values for *L. m. purpurescens* and supports my conclusion that these fish are progeny of the 1975 plant.

Southeastern bluegill entered the fishery in relatively small numbers in February 1977, accounting for 2.1% by number of panfish in the creel during the 1977 angler survey period. Green sunfish composed the remaining 97.9% of the panfish taken. The 28 bluegill observed in the creel during 1977 averaged 173 mm FL and ranged in length from 107–198 mm. The fish had a mean weight of 128 g and ranged from 30–200 g. All of these fish were determined by scale analysis to be from the 1975 year-class (Age II). Interviewed anglers expressed satisfaction with the size of harvested bluegill at Lake Perris.

Growth of the initial year class of southeastern bluegill at Lake Perris has been exceptional. The mean size of Age II bluegill reported here represents one of the most rapid growth rates reported in the literature for either the common or southeastern subspecies (Carlander 1977). Common bluegill growth rates in California for Age II fish are substantially less than that reported here, averaging 116 mm FL (Table 1).

TABLE 1. Mean Total Length of Selected Bluegill Populations in California.

Locality	*Length at second annulus (mm FL)*	*Source*
Millerton Lake	79	Miller 1971
Folsom Lake	79	Tharratt 1966
Sutherland Res.	132	La Faunce, et al. 1964
Pine Flat Res.	122	Miller 1971
Cachuma Res.[1]	86	Puckett 1965
Lower Otay Res.[1]	108	Puckett 1965
Clear Lake[2]	165	Murphy 1951
San Vicente Res.[2]	150	Bell 1959
Lake Havasu	128	Beland 1954
Lake Perris	173	Present Study

[1] Reported in TL, converted to FL as described in Carlander, 1977, pg. 75.

[2] Mean FL at capture during 3rd year of life.

Results of growth determinations thus far for southeastern bluegill are encouraging. Lake Perris, however, is a recently impounded reservoir, and rapid growth of a newly introduced species is not unexpected. A more intensive study of the Lake Perris population is in progress to further assess growth and other life history parameters of this subspecies. In addition, studies have been initiated to assess the growth characteristics of the common and southeastern forms under controlled conditions. If the results of further growth studies are favorable, southeastern bluegill may be more desirable than common bluegill in California lakes and reservoirs.

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REFERENCES

Avise, J. C., and M. H. Smith. 1974. Biochemical genetics of sunfish. I. Geographic variation and subspecific intergradation in the bluegill, *Lepomis macrochirus*. Evolution 28: 42–56.

Beland, R. D. 1954. Report of the fishery of the lower Colorado River—the Lake Havasu fishery. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 54-17. 42 pp.

———. 1960. History of the El Capitan Reservoir fishery, San Diego County 1955–1959. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 60-20. 31 pp.

Bell, R. R. 1959. The fishery of San Vicente Reservoir, San Diego County, California. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 59-17. 62 pp.

Brown, D., K. D. Aasen, and C. E. von Geldern, Jr. 1977. Alabama spotted bass grow at record rate in Lake Perris, California. Calif. Fish Game, 63(1):60–64

Carlander, K. D. 1977. Handbook of freshwater fishery biology. The Iowa State Univ. Press, Ames, Iowa. 431 pp.

Fast, A. W. 1966. Fisheries management of El Capitan Reservoir, San Diego County, California, 1970–1972. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 66-5. 29 pp.

Hubbs, C. L., and E. R. Allen. 1943. Fishes of Silver Springs, Florida. Fla. Acad. Sci., Proc. 6:110–130.

King, W. 1947. Important food and game fishes of North Carolina. Dept. of Conservation and Development, Division of Game and Inland Fisheries, State of North Carolina.

La Faunce, D. A., J. B. Kimsey, and H. K. Chadwick. 1964. The fishery at Sutherland Reservoir, San Diego County, California. Calif. Fish Game, 50(4):271–291.

Martin, R. A. 1963. Centrarchid fishes of the Genus *Lepomis* in Florida. Univ. of Miami, Masters Thesis. 189 pp.

Miller, E. E. 1971. The age and growth of centrarchid fishes in Millerton and Pine Flat Reservoirs, California. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 71-4. 17 pp.

Miller, R. T., and Howard E. Winn. 1951. Additions to the known fish fauna of Mexico: Three species and one subspecies from Sonora. Wash. Acad. Sci., J 41(2):83–84.

Murphy, G. I. 1951. The fishery of Clear Lake, Lake County, California. Calif. Fish Game, 37(4):439–484.

Puckett, L. K. 1965. The age and growth of bluegill, *Lepomis macrochirus*, at Cachuma Reservoir, Santa Barbara County, and Lower Otay Reservoir, San Diego County. Calif. Fish Game, Inland Fisheries Admin. Rep. No. 65-22. 13 pp.

Tharratt, R. C. 1966. The age and growth of centrarchid fishes in Folsom Lake, California. Calif. Fish Game 52(1):4–16.

—Francis D. Henry, Jr., California Department of Fish and Game, Chino Fisheries Base, Rt. 2, Bird Farm Rd. Chino, California 91710. Current address is: California Department of Fish and Game, Operations Research Branch, 2201 Garden Rd., Monterey, California 93940. *Accepted for publication March 1979.*

BOOK REVIEWS

Assessing the Effects of Power-Plant Induced Mortality on Fish Populations

Edited by Van Winkle; Pergamon Press, Inc., New York; 1977; 401pp; $25.00

This volume presents the proceedings of the conference sponsored by the U. S. Energy Research and Development Administration, Oak Ridge National Laboratory, and the Electric Power Research Institute. In the United States most concerns dealing with fish and power plants have historically concentrated upon the impacts of discharges of heated effluents. Recently, however, concerned scientists have begun to concentrate upon entrainment-induced mortalities of eggs and larvae.

The fundamental question asked at the conference was "How do mortality rates imposed by power plants on young fish affect adult population size?" During the conference five areas of activity germane to this question were considered: case histories; estimating population sizes and natural mortality rates, especially for young-of-the-year fish; evidence for and magnitude of compensation; design of monitoring programs and statistical analysis of data; and, assessing power plant impacts with simulation models. The participants were chosen because of their research contributions in one or more of these five areas.

Three of the papers deal with problems of west coast anadromous fish populations: salmon in the Columbia River, and striped bass in the Sacramento-San Joaquin Estuary, California. The two California papers were co-authored by H. K. Chadwick, D. E. Stevens, and L. W. Miller.

The state-of-the-art being what it is, the fundamental question remains unanswered. The papers presented, however, do provide important guideposts for these scientists and administrators faced with the problems inherent in attempting to lessen the biological impacts of power plants.

This volume, while dealing with a specialized area of research, represents an important reference for fishery scientists working with population estimation techiques, larval survival rates, sampling techniques, and population modeling, as well as the basic problems of power plant entrainment of eggs and larvae.—*Michael L. Johnson*

Wild Geese

By M. A. Ogilvie; Buteo Books, Vermillion, SD; 1978; 350 pp; illustrated; $25.00

Wild Geese is a veritable compendium of biological data pertaining to the true geese, *Branta* and *Anser,* of the world. With the exception of the atypical Hawaiian Goose, *Branta sandvicensis,* Ogilvie provides the reader with a thorough treatment of these genera, ranging in scope from etymology to exploitation. He has accomplished this by presenting material in a comparative format, rather than using the systematic approach of individual species accounts. The book consists of eight chapters, each dealing with a selected aspect, or several aspects, of goose biology including: Classification; Identification; Ecology, Food, and Feeding; Breeding; Counting, Ringing, and Population Dynamics; Distribution and Status; Migration; and Exploitation and Conservation.

Overall the book is excellent; however, I enjoyed several chapters in particular. For example, in the chapter on breeding Ogilvie presents a thorough review of the breeding ecology of wild geese. Factors such as nest placement and construction, timing of breeding, nesting behavior, courtship, and copulation are described in detail. Discussions of predation, social ecology, and fledging and add further to this excellent chapter.

The chapter on "Counting, Ringing, and Population Dynamics," is also an excellent chapter and will be of at least some practical value to almost all waterfowl biologists who read it. Included is a historical review of the study of goose population biology, beginning with the 1930 Black Brant census organized by James Moffitt of the California Department of Fish and Game. Modern day techniques, including rotary-wing and fixed wing aircraft surveys are described, and the merits of each method are evaluated. Also included are hints on how to make accurate and productive counts. The descriptions of methods of capturing, banding, and collaring wild geese are also of value. The chapter terminates with a good discussion of goose population dynamics, including such topics as recruitment and mortality, and those factors which appear most often to influence populations.

"Exploitation and Conservation" presents a very good discussion of the legislative history which has influenced the protection and management of waterfowl in North America and Europe. Many of the problems which continue to hinder adequate management are discussed. These problems are particularly common outside of North America. The problems encountered in Europe are primarily related to the complex political patterns existing there. In Asia, political problems, rather than patterns, appear to be a major hinderance to sound research and management. Ogilvie also discusses management regulations, crippling losses, future research and management goals, current refuge systems and their objectives, transplanted populations, and depredation problems and solutions. A species-by-species account of the current status and population trends of the various geese of the world concludes the chapter.

In all, M. A. Ogilvie has produced an excellent work which pulls into one volume much of the existing knowledge on the geese of the world. Including the Hawaiian Goose in this book would have made the work more complete, but would not necessarily have added much to the usefulness of the book. The text is well written, easily read, and is laced with British vernacular. It concludes with a philosophical statement reminiscent of Aldo Leopold: "The appeal of geese is to the senses of man, to his eyes, his ears, and to an inner feeling of aesthetic pleasure. That pleasure can come from the thrill of seeing a goose fall to one's gun, a fitting climax to a battle of wits between the geese and yourself. Alternatively it can stem from an emotion that combines the sheer delight to be gained from watching and hearing them with something less tangible yet somehow deeply gratifying, the sense of contact with the wildest of all wild birds, wild geese."

The reader, whether a professional waterfowl biologist, birdwatcher, naturalist, or waterfowler, will find a great deat of valuable information in this book. I strongly recommend this work as an addition to the literature on waterfowl biology and as a source of fascinating reading for interested laymen and professionals alike. In this day and age it is unusual to find something worth the price placed upon it; this book is well worth the $25.00 asked by the publisher.—*Vernon C. Bleich*

Marine Mammals

Edited by Delphine Haley; Pacific Search Press, Seattle, WA 98109; 1978; 256 pp; illustrated; $26.50.

It is not often that one has the opportunity to review a natural history book which covers its subjects with factual exactness, and, at the same time, presents a balance between hard facts and enlightened behavioral anecdotes of human experiences with many of the species described. Pacific Search Press, with the able editorship of well-known naturalist-writer Delphine Haley, has published this exceptional book describing all the marine mammals found in the eastern north Pacific Ocean. Twenty-two marine mammalogists were called upon to contribute their expertise, resulting in a thorough presentation of the pertinent aspects of life history, physiology, behavior, ecology, and evolutionary trends of 51 taxa (49 described species, one undescribed whale, and one subspecies) recorded for the area from the southern tip of Baja California west to the Leeward Islands of Hawaii and north into the Arctic Ocean. There is also reference to 11 additional taxa from the southern hemisphere and the north Atlantic Ocean. Thus this book includes a description of or reference to one-half of the world's marine mammals, several of which are cosmopolitan in distribution.

The excellently written preface and introduction by Haley sets the theme of the book, depicting the general evolution and adaptation of these fascinating and divergent forms. A brief resume of whaling practices and fur hunting leads into contemporary values wherein ecological concern has fostered appreciation of the aesthetic values of animals and the ecosystems of which they are in integral part. Haley's approach is welcomed in light of the recent plethora of overly emotional and anthropomorhic publications and articles written in response to our search for ecological awareness. As Haley states in the preface: "This book is factual in approach, centered . . . on what is known of the marine mammals. It contains no poems, no legends, no mystical stories—only facts. However, a lack of lyrics does not mean a lack of love—and facts have a certain practical eloquence all of their own. Surely it is this type of knowledge that will ultimately help us conserve the marine mammals that share our world."

There are either black and white or color photographs of all but three rare species of the 51 north Pacific taxa. Forty-three photographs are full page in the 8.5 by 11 inch format. There are 98 exceptionally clear and often highly artistic black and white photographs, 21 high quality color photographs, 12 drawings of the probable appearance of extinct species or their structures as well as several dozen artistic reproductions of whales and porpoises. There are range distribution maps for 42 species. Pacific coast shoreline observers will be especially interested in the chapters on the killer whale, California gray whale, the vocalizing humpback whale, the lovable harbor seal and sea otter, the comical, monstrous elephant seal, and the highly visible and vocal sea lions. There are little known bits of information such as the fact that the voice of the blue whale can travel across the expanse of an ocean, that whales may have adapted to the water from a land mammal of the Order Ungulata (a goat?), and that there were now extinct algae grazing animals similar to dugongs as well as walrus-type animals along the California coastline millions of years ago. Discussion of extinct species is a reminder that a vast multitude of animals have become extinct without the final push to oblivion coming from man. However, the highly-specialized Steller sea cow did become extinct shortly after western man discovered the last small stock at the Commander Islands in 1742. It was apparently delicious to eat.

Only one factual "error" came to the attention of the reviewer. This was the reference by Victor Scheffer about a killer whale attack on a human: the attack on a surfer near Monterey in 1972. This reviewer, immediately after the attack and in consultation with sharkologists, analyzed all information available, including the razorlike slits in the surfer's wet suit made by the teeth, and concluded

that the attacking animal was definitely a great white shark. Fortunately, and in keeping with the factual theme of the book, Scheffer did not have confirmation of the attack and qualified his report by asking, "Might it have been a shark?" It definitely was a shark, and the killer whale still has not achieved the ultimate "status" in animal predation, i.e., preying upon man.

Karl Kenyon's section on the sea otter is factual and relates several endearing behavioral experiences encountered during his long association with the animal. However, there is some reference to man-sea otter interactions that may be misinterpreted. Kenyon refers to the sea otter "conflict" as being between two opposing forces: the "Friends of the Sea Otter" and the "Friends of the Abalone". There has not been an organization that could be considered "Friends of the Abalone" for many years. Recently, a group of concerned recreational and commercial users of shellfish resources have joined forces who wish to protect both the sea otter and the remaining shellfish fisheries that the sea otter can preclude, i.e., clam, urchin, abalone, lobster, and certain crabs. Unfortunately, the high energy consuming sea otter is the one marine mammal that does present a serious threat to fisheries in the southern part of its range in Washington, Oregon, and California. If certain shellfish fisheries are to remain viable at least somewhere along the Pacific coastline, the otter must eventually be contained. Man cannot "compete" with the otter at the same time and place as may be incorrectly interpreted.

Of note to field naturalists and researchers: this book does relate diagnostic color patterns, size, and some morphological distinctions for use in identification, but it is not a field guide in that there are no diagnostic keys to the species and teeth numbers are given for only 6 species. Unfortunately, this book appeared at the time when there is a taxonomic debate as to whether the pinnipeds are in an Order of their own as they have been for many years (Order Pinnipedia) or are to now be included in Order Carnivora. Throughout the text they are referred to as pinnipeds but are designated as being in Order Carnivora in the introductory chapter on these animals and in the taxonomic listing of marine mammals. It would possibly have been proper, if one wishes to follow the new classification, to have included the Suborder Pinnipedia in the taxonomic listing and lessen the chance of confusion to the unaware.

In today's enlightened interest in marine mammals, this book should be included in every school and community library because of its factual, pictorial, and aesthetic value. The price may seem to be a bit stiff, but it is a bargain to any naturalist or student of marine life. It is a library of many books in one and includes new information that cannot be found elsewhere.—*Daniel J. Miller*

The Natural History of Native Fishes in the Death Valley System

By David L. Soltz and Robert J. Naiman; International Printing Services, Inc., c/o Book Shop, Natural History Museum of Los Angeles County, 900 Exposition Boulevard, Los Angeles, CA 90007; 1978; 76 pp; illustrated; $7.50.

Spawned along with the "Save the Pupfish" movement of a decade ago, this book represents perhaps the first popular work ever published in California relating solely to nongame fishes. The authors were graduate students at that time and have been active in the field of nongame fishes ever since. They have concisely presented a wealth of material ranging from Pleistocene hydrography through natural history and physiological ecology and ending with a highly pertinent chapter on the need for the conservation of desert fishes. Extensive preservation work undertaken to date is accurately described, and the reader is presented in the book's concluding sentence with a realistic and frightening challenge: "We must all make the decision [to preserve desert aquatic ecosystems], and it must be made soon, or there will be no native fishes of Death Valley."

The book is well arranged, and the authors have successfully translated the sometimes depressingly complicated jargon of the scientist (example: Physiological Ecology) into a language readily understood and enjoyable to the layman. The drawings are beautifully and accurately done, and a real bonus is provided in several superb underwater photographs by Alan Heller.

If there are criticisms of the book, they should be directed toward reproduction of some of the color photographs. In addition, the binding is less substantial than one should expect in a book of this price range. However, these are minor considerations. I challenge anyone to find an equal to the interesting and thought provoking information which Dave Soltz and Bob Naiman have presented so skillfully in just 76 pages.

Aldo Leopold stated in "A Sand County Almanac" that "The only true development in American recreational resources is the development of the perceptive faculty in Americans." There is no question that the key to the long term preservation of nongame fishes (and *all* life forms) lies in public enlightenment and support. "The Natural History of Native Fishes in the Death Valley System" makes a significant step toward the accomplishment of this objective.—*Phil Pister*

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